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and
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Founded by
LOUIS A. BAUER

Conducted by
J. A. FLEMING
Department Terrestrial Magnetism, Carnegie Institution of Washington, D. C.

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ON THE VARIATION OF MAGNETIC CHARACTER-NUMBERS AT DOMBÅS OBSERVATORY

BY K. F. WASSERFALL

The international character-number, C, was introduced in 1906. The meeting of the Magnetic Commission in September 1905 agreed on the following scale of classification, proposed by Ad. Schmidt: "0" = quiet days; "1" = disturbed days; "2" = very disturbed days. It was left to the discretion of individual directors to fix limits for defining these divisions [see 1 of "References" at end of paper]. The data for the individual observatories are tabulated at De Bilt, the daily mean values being expressed in tenths of the unit used by the observatories. Also are given monthly and yearly mean figures—expressed to the second decimal of the original unit. In 1917 thirty-eight observatories sent in such lists, and in 1938 forty-six stations contributed.

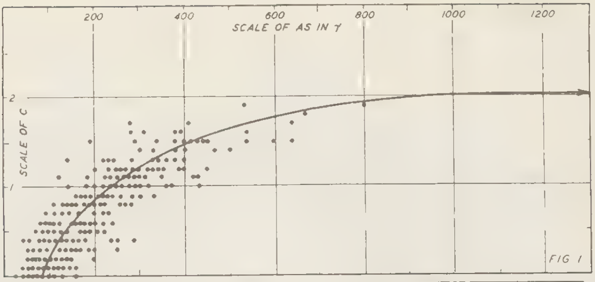
As to the method used for classification, the so-called "Potsdam-method," which depends on judgment, based on inspection of the photograms from day to day, is in most general use. Some observatories use a method of classification based on the actual measurement of the daily range, etc. Tromsö Observatory uses the quantity AS, which stands for *absolute storminess*—the sum of the deflections in gammas of the 24 hourly means of the day from a normal line representing undisturbed conditions. For the data for C, given by Tromsö, only AS for H, the most disturbed component, is considered.

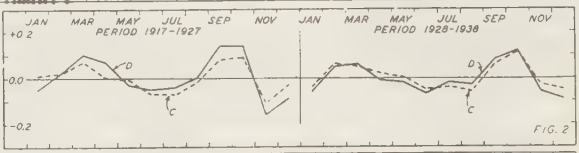
The character-number for Dombås Observatory is also based on AS, but not on AS for H but on AS for D. In a paper, in which the most characteristic features in the variation of the Dombås material were treated [2], a graphical comparison was made between data for AS for the three elements D, H, and V and the character-figure, C, plotted with monthly mean values during the epoch 1923-33. This comparison showed that AS for D seems to be the best quantity for deriving data for C, if we wish the highest possible agreement. Therefore, the daily data for C for Dombås have been taken from the average curve shown in Figure 1.

Table 1 shows the good agreement between monthly mean values for 1937 of character-figures, D, at Dombås and the international character-figure, C.

TABLE 1—*Comparison of monthly mean magnetic character-figures for 1937*

Source	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Dombås	0.59	0.78	0.81	0.80	0.79	0.81	0.82	0.74	0.67	0.92	0.70	0.61	0.75
International	0.55	0.89	0.78	0.83	0.74	0.74	0.78	0.53	0.61	0.98	0.73	0.63	0.73





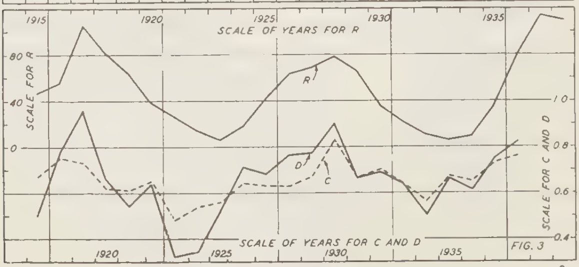


FIG. 1—RELATION BETWEEN ABSOLUTE STORMINESS (AS) FOR DECLINATION AT DOMBÅS FOR 1933 AND CORRESPONDING DATA FOR INTERNATIONAL MAGNETIC CHARACTER-NUMBERS (C)

FIG. 2—MONTHLY MEAN DEPARTURES FROM MEAN ANNUAL MAGNETIC CHARACTER-FIGURES, DOMBÅS (D) AND INTERNATIONAL (C)

FIG. 3—MEAN ANNUAL VALUES OF CHARACTER-FIGURES, 1917-1938, DOMBÅS (D) AND INTERNATIONAL (C), AND OF SUNSPOTS (R)

The Dombås material for 1917-38 includes two 11-year periods. It may therefore be of some interest to examine the variation of the character-figures for this station —especially since they are based on a method of classification not used by any other observatory. Table 2 summarizes the monthly mean values for D (that is, C as based on absolute storminess in declination at Dombås) for the two 11-year periods 1917-27 and 1928-38. A few days are missing in May 1919, May 1924, July 1923, and September 1917, and there are no data for the whole month of October 1919. The original data for AS will be found in references [3] to [5].

In the first place, let us inspect the annual variation of the character-numbers plotted graphically in Figure 2. The full-line graphs are for Dombås for 1917-27 and 1928-38, and the dotted ones are the international character-figures as given in Table 3.

The graphs show good agreement. The high values at the time of the equinoxes and low values at the end and in the middle of the year are in good agreement with what has been shown by Bartels [6].

ABLE 2—*Monthly means magnetic character-figure, D, based on absolute storminess in declination at Dombås, 1917-27* and *1928-38*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1917	0.61	0.39	0.31	0.37	0.35	0.34	0.38	0.66	0.75*	0.85	0.42	0.58	0.50
1918	0.62	0.82	0.70	1.02	0.64	0.61	0.68	0.66	0.95	0.87	0.78	0.96	0.78
1919	0.86	1.02	1.19	0.94	1.16*	0.89	0.88	1.09	1.13	1.16*	0.50	0.68	0.96
1920	0.69	0.72	0.99	0.86	0.54	0.36	0.60	0.58	0.97	0.64	0.49	0.48	0.66
1921	0.32	0.35	0.55	0.67	0.76	0.37	0.50	0.59	0.53	0.63	0.56	0.62	0.54
1922	0.61	0.86	0.81	0.88	0.57	0.63	0.67	0.64	0.67	0.73	0.38	0.26	0.64
1923	0.22	0.45	0.42	0.37	0.30	0.39	0.26*	0.20	0.30	0.40	0.24	0.27	0.32
1924	0.40	0.31	0.46	0.22	0.22*	0.44	0.42	0.28	0.50	0.27	0.32	0.23	0.34
1925	0.35	0.30	0.36	0.48	0.45	0.74	0.49	0.69	0.70	0.75	0.47	0.51	0.52
1926	0.83	0.92	0.94	0.87	0.65	0.61	0.61	0.55	0.79	0.96	0.38	0.41	0.71
1927	0.54	0.63	0.96	0.71	0.67	0.68	0.67	0.63	0.81	0.88	0.35	0.61	0.68
Mean	0.55	0.62	0.70	0.67	0.57	0.55	0.56	0.60	0.74	0.74	0.44	0.51	0.60
1928	0.48	0.64	0.65	0.71	0.87	0.80	0.93	0.70	0.88	0.96	0.84	0.63	0.76
1929	0.50	0.88	0.90	0.57	0.65	0.63	0.81	0.62	1.00	1.04	0.74	0.83	0.77
1930	0.86	0.90	0.88	1.14	0.87	0.90	0.93	0.94	0.98	1.09	0.72	0.61	0.90
1931	0.55	0.60	0.58	0.41	0.50	0.60	0.57	0.75	0.85	0.99	0.79	0.73	0.66
1932	0.74	0.83	1.04	0.90	0.80	0.40	0.51	0.54	0.71	0.70	0.51	0.63	0.69
1933	0.58	0.69	0.67	0.77	0.64	0.59	0.54	0.67	0.75	0.57	0.67	0.49	0.64
1934	0.36	0.56	0.71	0.43	0.43	0.43	0.34	0.68	0.65	0.50	0.35	0.56	0.50
1935	0.67	0.85	0.82	0.48	0.50	0.62	0.55	0.50	0.99	0.80	0.56	0.64	0.66
1936	0.77	0.87	0.66	0.80	0.67	0.55	0.65	0.49	0.41	0.55	0.57	0.37	0.61
1937	0.59	0.78	0.81	0.80	0.79	0.81	0.82	0.74	0.67	0.92	0.70	0.61	0.75
1938	1.09	0.77	0.78	0.74	0.84	0.72	0.96	0.86	0.77	0.98	0.71	0.67	0.82
Mean	0.65	0.76	0.77	0.70	0.69	0.64	0.69	0.68	0.79	0.83	0.65	0.62	0.71

*Interpolated values.

TABLE 3—*Monthly means international magnetic character-figure, C, 1917-27 and 1928-38*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1917	0.81	0.69	0.59	0.63	0.66	0.55	0.61	0.85	0.61	0.74	0.53	0.72	0.67
1918	0.63	0.78	0.73	0.79	0.68	0.56	0.69	0.77	0.88	0.85	0.77	0.88	0.75
1919	0.78	0.81	0.89	0.70	0.82	0.55	0.54	0.70	0.83	0.91	0.52	0.66	0.73
1920	0.62	0.52	0.78	0.65	0.57	0.43	0.51	0.61	0.87	0.65	0.58	0.65	0.62
1921	0.54	0.51	0.68	0.67	0.83	0.55	0.54	0.58	0.50	0.63	0.62	0.65	0.61
1922	0.65	0.74	0.79	0.75	0.57	0.62	0.66	0.71	0.69	0.68	0.47	0.42	0.65
1923	0.48	0.61	0.53	0.44	0.47	0.50	0.42	0.36	0.52	0.55	0.42	0.50	0.48
1924	0.64	0.56	0.64	0.43	0.54	0.64	0.55	0.41	0.67	0.52	0.54	0.40	0.54
1925	0.44	0.42	0.42	0.52	0.47	0.74	0.55	0.61	0.71	0.82	0.48	0.57	0.56
1926	0.84	0.85	0.85	0.75	0.60	0.53	0.49	0.50	0.75	0.67	0.46	0.54	0.64
1927	0.62	0.66	0.80	0.60	0.65	0.47	0.56	0.61	0.77	0.84	0.35	0.63	0.63
Mean	0.64	0.65	0.70	0.63	0.62	0.56	0.56	0.61	0.71	0.72	0.52	0.60	0.63
1928	0.44	0.62	0.48	0.52	0.75	0.72	0.72	0.56	0.75	0.83	0.65	0.54	0.63
1929	0.47	0.82	0.85	0.54	0.61	0.56	0.66	0.55	0.75	0.85	0.71	0.71	0.67
1930	0.69	0.89	0.90	1.04	0.93	0.87	0.87	0.88	0.85	0.88	0.61	0.54	0.83
1931	0.54	0.62	0.59	0.45	0.54	0.65	0.55	0.68	0.82	0.95	0.83	0.74	0.66
1932	0.76	0.76	0.95	0.89	0.80	0.43	0.49	0.67	0.73	0.73	0.58	0.67	0.70
1933	0.65	0.65	0.71	0.76	0.62	0.55	0.54	0.60	0.77	0.65	0.63	0.53	0.64
1934	0.52	0.65	0.76	0.45	0.51	0.44	0.43	0.68	0.68	0.50	0.39	0.66	0.56
1935	0.69	0.72	0.73	0.55	0.51	0.68	0.56	0.51	0.86	0.86	0.65	0.73	0.67
1936	0.69	0.78	0.64	0.82	0.70	0.69	0.73	0.45	0.46	0.69	0.70	0.47	0.65
1937	0.55	0.89	0.78	0.83	0.74	0.74	0.78	0.53	0.61	0.98	0.73	0.63	0.73
1938	1.08	0.79	0.65	0.80	0.76	0.57	0.73	0.73	0.83	0.81	0.67	0.66	0.76
Mean	0.64	0.74	0.73	0.70	0.68	0.63	0.64	0.62	0.74	0.79	0.65	0.63	0.68

As regards variation from year to year of the annual mean figures for D and for C (Tables 2 and 3), we note that the agreement between D and C is not so good as that shown in Figure 2. The mean annual values are plotted in Figure 3.

Inspection of Figure 3 shows that the agreement between the curve for Dombås and that for the international figures is very good from 1926 to 1938, the greatest departure being only 0.13 unit (1928). During 1917 to 1925 the departures are considerably greater; this might indicate that the series of figures are somewhat inhomogeneous. As already noted, some interpolations had to be made for the Dombås data; however, it seems unlikely that possible errors at Dombås are responsible. Errors in the scale-value for the declination-curve might seem to offer a most reasonable explanation, but close examination of the data used for ϵ_D apparently excludes this possibility.

Bartels suggests [6] that there seems to be a break in the homogeneity of the international figures, when the year-to-year series are considered. This lack of homogeneity in C, however, is apparently disproved by van Dijk [7]. However this may be, we limit the discussion here to the very high value of D for 1919 and the low values of D for 1917, 1923, and 1924 in comparison with C.

Figure 3 includes a graph of sunspots for 1915-38. To mark the parallelism in the 11-year period of sunspots with the two magnetic curves, the scale of years is displaced two years. No opinion is ventured regarding physical justification of this displacement.

References

[1] Report of the International Meteorological Conferences at Innsbruck, September 1905 (1908).

[2] K. F. Wasserfall, Some of the most characteristic features in the variation of magnetic elements, Pub. Inst. Kosmisk Fysikk, No. 10 (1937).

[3] O. Krogness and K. F. Wasserfall, Results from the magnetic station at Dombås 1916-33, Pub. Inst. Kosmisk Fysikk, No. 9 (1936).

[4] B. Trumpy and K. F. Wasserfall, Results from the magnetic station at Dombås 1934-36, Pub. Inst. Kosmisk Fysikk, No. 13 (1938).

[5] B. Trumpy and K. F. Wasserfall, Results from the magnetic station at Dombås 1937-38 (in preparation).

[6] J. Bartels, Terrestrial-magnetic activity and its relations to solar phenomena, Terr. Mag., **37**, 1-52 (1932).

[7] G. van Dijk, Measures of terrestrial-magnetic activity, Terr. Mag., **40**, 371-380 (1935).

Det Magnetiske Byrå,
Bergen, October, 1939

ON SOME RECENTLY DETECTED IMPORTANT VARIATIONS WITHIN THE AURORAL SPECTRUM

By L. Vegard

§1. *Indications of hydrogen-showers in the auroral region*– As pointed out in previous papers [see 1, 2, 3 of "References" at end of paper] lines from hydrogen do not ordinarily appear in the auroral spectrum. Even spectra which in the regions, where the Balmer lines appear, give very weak auroral lines or bands do not show any trace of the hydrogen-series. Spectrograms obtained with large dispersion giving with great density the red bands of the first positive group near the red Balmer line do not show any trace of H_α [4].

As pointed out by the writer [3] this does not mean that hydrogen may not occasionally appear in the upper atmosphere. On the contrary, the writer proposed an explanation of the luminous night clouds [3], according to which these clouds—situated at an altitude of about 80 km —were due to precipitations (showers) of hydrogen coming in from space, and originating in the Sun. When these showers enter the atmosphere, hydrogen, probably in the form of atoms, combines with oxygen existing, for example, in the form of atoms or ozone to form water-vapor. At the altitude of 80 km the pressure in the atmosphere may be sufficiently large for the water-vapor to condense to form clouds consisting of ice-needles.

During an auroral display observed at Oslo on the evening of October 18, 1939, we obtained from quiet auroral arcs two spectrograms of a peculiar type indicating the existence of such hydrogen-showers.

In the region of long waves the spectrograms showed the green OI-line (5577) and the strongest component (6300) of the OI-triplet with great density, while bands of the first positive group usually found under such conditions were absent. Far out in the red part, however, and well separated from the red OI-line, a strong line appeared. Wave-length measurements showed that this line within the limit of error coincided with H_α, ($\lambda = 6562.8$). As the dispersion of the instrument is small especially towards long waves, the error may be several Å-units and therefore this coincidence is not conclusive.

On the first of our spectrograms (for which the exposure lasted from $19^h\,15^m$ to $20^h\,13^m$ MET) another line which is usually absent in the auroral spectrum appeared in the blue part, and it was found that this line within the limit of error coincides with H_β ($\lambda = 4861.3$). This line appeared quite weak on the spectrogram but it was stronger than the negative band 4708.

A microphotometric curve of the spectrum is shown in Figure 1, and a reproduction of three spectrograms obtained that evening is shown in Figure 2 (spectrogram *B*1). The maximum corresponding to H_α is seen in Figure 1 to be very strong, while that corresponding to H_β is weak, but is clearly marked. The relative intensities of the lines and bands were measured and the results are given in Table 1.

Table 1

Vave-length, λ	6563	6300	5577	4861	4708	4278	3914
nterpretation	H_α	OI ($^1D_2 - {}^3P_2$)	OI ($^1S_0 - {}^1D_2$)	H_β	NG (0, 2)	NG (0, 1)	NG (0, 0)
ntensity	41.5	33.5	196	7.1	3.6	10	15

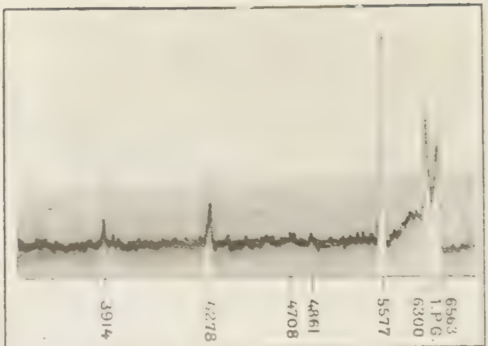


FIG. 1—MICROPHOTOMETRIC CURVE OF AURORAL SPECTRUM AT OSLO, OCTOBER 18, 1939

The line 4861 is also just visible on the spectrogram A1 of Figure 3 taken September 19, 1939.

The simultaneous enhancement of two lines, one of which coincides with H_α, the other with H_β, can hardly be accidental, and our spectrograms thus would *give evidence of a situation where considerable quantities of hydrogen are present in the auroral region.* The numerous auroral spectrograms obtained during recent years, where the hydrogen lines are absent, show that noticeable quantities of hydrogen are only found in the upper atmosphere on rare occasions. *Thus the occurrence of H-lines must be due to showers of hydrogen or to a kind of "hydrogen-radiation" occasionally coming from the Sun.*

A second spectrogram (B2 of Fig. 3) obtained on the same evening from $20^h 13^m$ to $20^h 47^m$ showed the H_α-maximum quite distinctly, but as the spectrogram was weaker the H_β-maximum was not apparent.

A third spectrogram (B3 of Fig. 3) from $20^h 47^m$ to $21^h 55^m$ corresponding to the upper limit of auroral rays showed an enhanced red OI-line (6300), but the H_α- and H_β-maxima were absent. This might indicate that the "hydrogen-effect" is mostly restricted to the lower region, because the luminescence from arcs is mainly restricted to regions near the lower limit which is usually situated at altitudes of about 100 km.

§2. *Variation of the auroral spectrum with latitude*—A comparison between spectrograms occasionally obtained at Tromsö with those obtained at Oslo has indicated [3] that the intensity of the red OI-line (6300) compared with that of the green line is relatively greater at Oslo. This means that the relative intensity of the red OI-line and the frequency of red auroras of type *A* increase as we approach lower latitudes.

In January, 1926, when spectrograms of a red aurora of type *A* were obtained at Oslo [5], spectrograms were obtained with an almost identical equipment at Tromsö during the same night. Although the red OI-line appeared also at Tromsö with unusual strength, its intensity relative to that of the green line was much smaller than that found at Oslo during the same time-interval.

It therefore became a matter of importance to study in a more sys-

tematic way the possible variation with latitude of the intensity-distribution within the auroral spectrum. Mainly for this purpose a number of spectrograms were taken at the Auroral Observatory at Tromsö by my assistant O. Krogness, Jr., while we were obtaining as many spectrograms as possible also at Oslo by means of a small spectrograph almost identical with that used at Tromsö. These spectrograms were taken on panchromatic plates.

The true relative intensities were found by photographing with each spectrograph on the plates used, spectrograms from a light-source of known intensity-distribution. The procedure used for the measurements of relative intensities has been dealt with in previous papers [2, 6].

At Tromsö we have measured 27 spectrograms obtained from October to December, 1938, and 26 spectrograms obtained at Oslo during 1938-39. For each locality we have calculated the mean relative intensity for a number of the more conspicuous bands and lines. The results are collected in Table 2.

TABLE 2

λ	Tromsö, 1938	Tromsö, previously measured	Tromsö, mean values	Oslo, 1938-39	$I_{Oslo}/I_{Tromsö}$
b 6300	30.7	28	29.4	103	3.4
5990	12.8	15	14	(28)	2.2
a 5577	108.2	100	104	178	1.7
5238	4.0	6.0	5.0		
c 4708	6.7	7.8	7.3	10	1.5
4650	2.4	4.6	3.5		
d 4278	24.4	24.4	24.4	24.4	1.0
4058	2.2	3.4	2.8		
3998	3.4	3.7	3.5		
e 3914	66	47.4	56.7	39.2	0.59

The first column gives the wave-length and the second the mean intensity-distribution found from the Tromsö spectrograms of 1938. In the third column is entered the relative intensity found from previous spectrograms, most of which were obtained with large spectrographs and exposures usually lasting for several weeks. A comparison of columns 2 and 3 shows that the mean intensity-distribution derived from spectrographs of small dispersion and short exposures does not differ much from that obtained by means of long exposures with spectrographs of much larger dispersion.

The fourth column gives the mean of the values given in columns 2 and 3. Column 5 contains the values found from the Oslo spectrograms.

The intensity-distribution at Oslo and Tromsö for the two strong OI-lines and three negative bands is represented in Figure 2.

We found it most suitable for our purpose to use the negative nitrogen band 4278 as a standard of comparison. In earlier tables, where the intensity of the green line was given the arbitrary value 100, the band 4278 had the value 24.4 and this value was used also for the later observations.

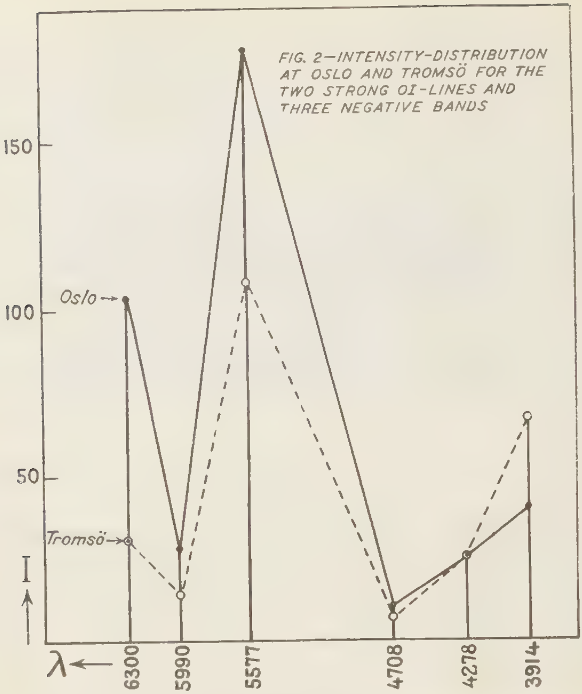


FIG. 2—INTENSITY-DISTRIBUTION AT OSLO AND TROMSÖ FOR THE TWO STRONG OI-LINES AND THREE NEGATIVE BANDS

Table 2 and Figure 2 show some very conspicuous variations with latitude of the intensity-distribution within the auroral spectrum. The most important latitude variations are:

(1) *The intensity of the red OI-triplet, relative to that of the green line and still more relative to that of the negative bands, increases towards lower latitudes.* The ratio I_{6300} I_{5577} is nearly twice as large at Oslo as at Tromsö despite the fact that most auroras at Oslo have appeared far down on the northern horizon, so the observations at Oslo on an average correspond to the latitude near that of Trondheim.

2. *The intensity of the green line relative to that of the negative bands increases towards lower latitudes.* The effect derived from the present material is very marked, the relative intensity of the green line at Oslo being 1.7 times that at Tromsö.

3. *The intensities of the negative bands belonging to the vibrational series (o, n) seem to diminish more rapidly with increasing (n) at Tromsö than at Oslo. Certain other observations indicate that the intensities of bands of the sequence $n''-n'=2$ decreases less rapidly with increasing quantum number (n) at Oslo than at Tromsö.*

From the enhancement of the red line during periods of high sunspot-frequency and in an atmosphere exposed to sunlight, the writer concluded

that the red line to a large extent results from an excitation-process which brings the OI-atom to the $^1D_2$-state without passing the $^1S_0$-state, and further that the enhancement is probably connected with some change in the state and composition of the upper atmosphere.

These results are confirmed by the latitude-effects which show that *the excitation-processes for both the green line and the red triplet if not due to a change with latitude of the properties of the solar electric rays must be intimately connected with the presence of atmospheric components, the concentration of which is altered by some kind of solar radiation.* These changes in the atmospheric composition may consist in the formation of ozone and of atomic oxygen and nitrogen.

The fact that the intensity of the OI-lines increases towards lower latitudes, shows that the solar radiation which is effective in producing these variations, is not deviated in the magnetic field of the Earth. It is not a radiation composed of moving electric particles, but it must be a radiation of short wave-length. The considerable enhancement of the red line with sunspot-frequency shows that the radiation producing the atmospheric changes and the enhancement-effect must be one which is essentially attached to solar activity. *It cannot be only the ultraviolet part of the temperature radiation, but mainly the radiation of the X-ray type, the existence of which has been assumed to account for the distribution of matter and ions in the auroral region.*

§3. *Further observations of the altitude-effects shown by the red OI-line and by bands of the first positive group*—During the last two years observations have been continued at Oslo with the object of studying the change of intensity-distribution with altitude, especially the change of the relative intensity of the red line and the first positive group. For this purpose we took pairs of spectrograms for which one corresponds to the upper and one to the lower limit of auroral ray-streamers. During the autumn of 1938 we measured four pairs and during 1939 also four sets of spectrograms. The results are given in Table 3.

TABLE 3

Year	$R=(I_{6300}/I_{5577})$		(R_u/R_l)
	Upper limit	Lower limit	
1938	119	53.5	2.2
1939	97.6	29.2	3.3
Mean	108	41	2.6

The results given in Table 3 confirm the results previously obtained [7, 8, 9] regarding the enhancement of the red line 6300 $(\mathrm{OI}(^1D_2-{}^3P_2))$ relative to the green line $\mathrm{OI}(^1S_0-{}^1D_2)$ with increasing altitude.

On a number of pairs of spectrograms obtained at Oslo October 11-12, 1937, it was found that the intensity of the first positive group diminished upwards [9]. While the typical red bands of this group appeared with considerable photographic density on the spectrograms for the lower limit, they were too weak to be observed on the spectro-

grams corresponding to the upper limit. Although these spectrograms showed the altitude-effect of the first positive group, they gave no possibility for quantitative determination of its magnitude.

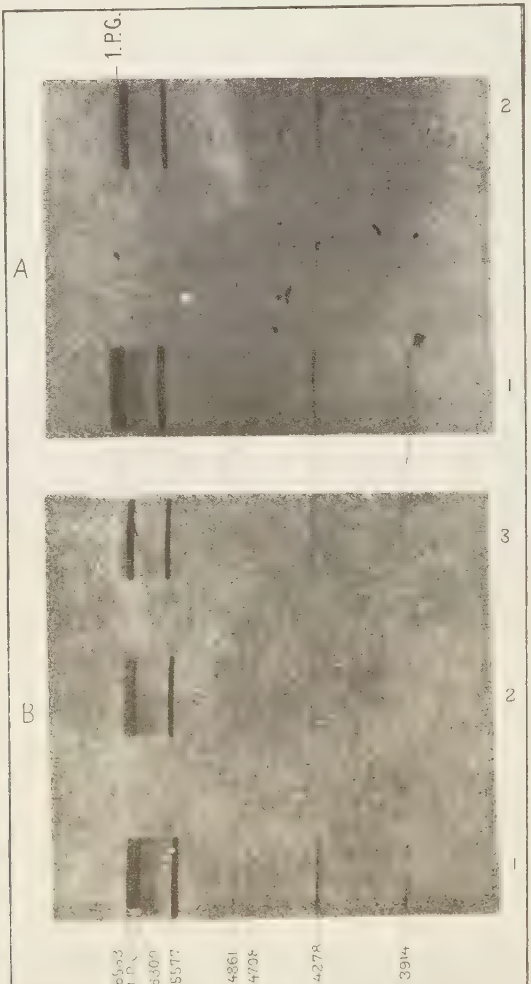


FIG. 3—SPECTROGRAMS TAKEN AT OSLO DURING AUTUMN 1939 WITH SMALL GLASS SPECTROGRAPH ON AGFA ISOPAN ISS PLATES: A, SEPTEMBER 19 [2, 20^h50^m TO 22^h20^m (UPPER LIMIT OF RAYS); 1, 22^h20^m TO 23^h20^m (LOWER LIMIT OF ARC AND RAYS)] B, OCTOBER 18 [1, 19^h15^m TO 20^h13^m (LOWER LIMIT OF ARCS); 2, 20^h13^m TO 20^h47^m (LOWER LIMIT OF ARCS); 3, 20^h47^m TO 21^h55^m (UPPER LIMIT OF RAYS)]

During an auroral display occurring on September 19, 1939, we obtained at Oslo a pair of spectrograms ($A1$ and $A2$ of Fig. 3) where the first positive group also appeared on the spectrogram corresponding to the upper limit, and from this pair of spectrograms, it was possible to measure the altitude-effect of the first positive group. The intensity-distribution corrected for extinction for the two spectrograms is given in Table 4 for some of the strongest bands and lines observed.

TABLE 4

λ, first positive group maximum	I corrected for extinction		(I_u/I_l)
	Exposure upper limit	Exposure lower limit $22^h\,20^m$ to $23^h\,20^m$	
6500	23.1	32.3	0.71
6300	100	51.5	1.94
5577	76.8	101	0.76
4708	weak	3.6	....
4278	10	10	1.0
3914	14	14	1.0

In this Table the intensity of the negative band 4278 has been put equal to 10. The altitude-effects are clearly seen from the last column giving the ratio $I_{\text{upper}}/I_{\text{lower}}$ for the lines and bands measured.

The Table shows first of all the altitude-effect of the green line which was detected and measured by the writer in 1923, and which expresses the fact that *the intensity of the green line relative to that of the negative bands diminishes towards greater altitudes. It expresses a large enhancement of the red line 6300 relative to the negative bands. Finally the measurements gave the result that the intensity of the bands of the first positive group compared with that of the negative bands decreases upwards. In our case we find* $I_u/I_l=0.71$.

It should be remembered that the magnitude of this last effect largely depends on the average altitude of the light from the lower limit. The red auroras of type B with a red lower border, which owe their redness to the enhancement of the first positive group, shows that the relative intensity of the first positive group increases very rapidly when we pass down below say 110 km.

Height measurements of red auroras of type B carried out by Harang and Bauer [10] show that this type may reach down to the exceptionally low altitudes of 65 to 70 km. This means that on account of the altitude-effect of the first positive group, the red bands of this group increase so rapidly below 100 km as to give the total luminescence an intensive red color.

References

[1] L. Vegard, Vid. Akad. Skr., I, Nos. 8, 9, and 10 (1923); Phil. Mag., **46**, 193-211 (1923); Zs. Physik, **16**, 367-390 (1923).

[2] L. Vegard, Geofys. Pub., **9**, No. 11 (1932).

[3] L. Vegard, Geofys. Pub., **10**, No. 4 (1933).

[4] L. Vegard and L. Harang, Geofys. Pub., **11**, No. 15 (1937).
[5] L. Vegard, Avh. Norsk Vid. Akad., I, No. 2 (1926); Nature **117**, 356 (1926).
[6] L. Vegard and E. Tönsberg, Geofys. Pub., **11**, No. 16 (1937).
[7] L. Vegard, Nature, **138**, 930-931 (1936).
[8] L. Vegard, Zs. Physik, **106**, 108-131 (1937).
[9] L. Vegard, Geofys. Pub., **12**, No. 5 (1938).
[10] L. Harang and W. Bauer, Gerlands Beitr. Geophysik, **37**, 109-115 (1932).

Physical Institute, University,
Oslo, Norway, November, 1939

AURORAS AND SUNSPOTS

By H. Helm Clayton

In the hope of advancing our knowledge of the relationship between sunspots and auroral displays the author has undertaken a study of the 55-year record of auroras observed at the Blue Hill Meteorological Observatory near Boston, Massachusetts. These data cover the period from from 1885 to 1939 and were kindly furnished by Dr. C. F. Brooks, the present director. In handling these data all doubtful cases were eliminated. Also, one date was assigned to all cases where the aurora was observed until after midnight. Thus an aurora observed from 20^h of September 15 to 2^h of September 16 was assigned to the night of September 15. In cases where the aurora was not observed until after midnight as, for example, September 16, 1^h to 2^h, it was assigned to the night of September 15. The auroras were observed to three degrees of intensity, namely 0, 1, and 2, and the intensity was taken at the time when the aurora was at its brightest. It is difficult to distinguish auroras of intensity 0 from the glare of the lights over Boston and for this reason most of the research deals with auroras of intensity 1 and 2.

The auroras thus arranged show a marked double annual period. The frequency of occurrence each month was as in Table 1 where minima are indicated by italic type and maxima by bold-face type.

Table 1—*Frequency of auroras at Blue Hill, Massachusetts, 1885-1939*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
13	23	**34**	33	23	*13*	21	21	**32**	31	*13*	14

These numbers are the total numbers for each month for 55 years. They show maxima in March and September and minima in November and June. This period is substantially the same period as that shown by magnetic variations and by electrical disturbances showing a connection with sunspots such as radio transmission and earth-currents.

There is a very evident connection of the auroral displays with sunspots. Taking the years of sunspot-maxima as 1883, 1893, 1906, 1917, 1928, and 1937, the frequency of auroras for each year of the sunspot-period is as in Table 2.

Table 2—*Frequency of auroras at Blue Hill, Massachusetts, as related to sunspot-maxima of 1883, 1893, 1906, 1917, 1928, and 1937*

Item	Years before				Max.	Years after					
	−4	−3	−2	−1	0	1	2	3	4	5	6
Totals	4	13	23	45	30	**46**	44	21	25	15	6
Means	0.8	2.6	4.6	9.0	6.0	**9.2**	8.8	4.2	5.0	3.0	1.2

The sums are for five sunspot-periods and show a maximum of auroras one year after sunspot-maximum. This delay was noted by Dr. Harlan T. Stetson in a recent issue of Science[1] and is clearly evident in the table

[1]H. T. Stetson, The present state of solar activity and associated phenomena, Science, 90, 482-484 (1939).

of C. Chree in the Encyclopedia Britannica. A delay, or lag, of about one year is also shown by other electric and magnetic conditions associated with sunspots.[2]

The next step was to investigate the relation of auroras to the position of sunspots or sunspot-groups seen on the face of the Sun. It has been suspected that auroras occur most frequently when sunspots or sunspot-groups cross the central area of the Sun.[3]

In order to test this supposition the relative sunspot-numbers within a central zone equal to one half the Sun's radius were used. These numbers were published by the solar observatory of Zurich, Switzerland, 1917-38. Table 3 was prepared in which was entered the sunspot-count for the day of the aurora and for each day up to five days preceding and following the aurora.

TABLE 3—*Sunspot-numbers in central area of Sun preceding and following auroras*

Item	Days before −5	−4	−3	−2	−1	Day of aurora 0	Days after 1	2	3	4	5	Case
Means	27.4	30.4	32.8	36.2	36.2	37.0	31.1	28.3	26.6	25.4	24.0	81
3-day means	....	30.2	33.1	35.1	**36.5**	34.8	32.1	28.7	26.8	25.3	....	..

This tabulation took all the auroras of intensity 1 and 2 for 55 years. The smoothed means show a maximum of spots in the central area of the Sun one day preceding the occurrence of the aurora.

Next the area of sunspots measured within a zone 14° wide, namely, within 7° of the central meridian of the Sun, was taken from the tables prepared by the United States Naval Observatory and published in the "Monthly Weather Review." The data were read from the tables and tabulated in the same way as in Table 3. These tables covered the interval from January 1927 to October 1939. The mean area for each day preceding and following the auroras was as follows:

TABLE 4—*Mean areas of spots preceding and following auroras*

Auroral intensity	Days preceding −5	−4	−3	−2	−1	Day of aurora 0	Days following 1	2	3	4	5	Cases
Medium	105	78	42	83	**178**	88	84	73	114	83	58	25
Brilliant	85	**380**	92	**330**	126	160	261	93	255	76	151	14

The areas are in millionths of the total area of the Sun's surface. The mass of data was not sufficient to bring out clearly the relationship, but indicates that the greatest area of spots in the central zone of the Sun preceded the aurora by from one to four days.

[2] H. W. Fisk, The lag between solar activity and magnetic activity, Terr. Mag., **34**, 147-150 (1929).
[3] H. H. Clayton, Auroras and sunspots, Science, N. S., **18**, 632 (1903).

Table 4 shows also that the area of spots preceding brilliant auroras (intensity 2) are much larger than the area of the spots preceding auroras of medium intensity. It is evident that the effects of the larger spots last longer, so that they may continue to produce auroral displays until four days or more after the central passage.

The next step was to try to find the effect of distance of the spots from the center of the Sun's disk during the central passage of the spots. In order to find this distance it is necessary to correct the latitude of the spots by the amount of tilting of the Sun's equator to the ecliptic or plane of the Earth's equator. The amount of this tilting for different times of the year is given in "Ephemeris for physical observations of the Sun" in the Nautical Almanac. This amount was applied as a correction to the latitude of the spots at zero longitude as determined from the solar data published by the Naval Observatory in the "Monthly Weather Review."

Since it was found that the size of the spots was important and that there is a delay after the central passage of the spots before the occurrence of the aurora, another arrangement was tried. The spots were arranged in groups according to their distance from the center of the solar disk when crossing the central meridian, namely, 0° to 15°, 16° to 30°, and 31° to 45°. The largest group of spots in each area on the day of the aurora or on any of the five days preceding the aurora was tabulated and means obtained as in Table 5.

TABLE 5—*Mean areas of spots crossing central meridian at different distances from center of Sun's disk*

Distance from center	Area of spots	No. of cases
0° to 15°	393	25
16 to 30	846	15
31 to 45	1110	4

It is evident from Table 5 that in order to produce auroras the area of spots passing the central meridian of the Sun must increase in size as distance from the center of the disk increases. When the spots are as much as 30° from the center the spots must be very large in order to produce auroras. When large spots pass within 20° of the Sun's center the auroras are frequently brilliant. Much smaller spots passing near the Sun's center may produce auroras of lesser intensity.

The position of these spots in relation to the central meridian is shown by Table 6.

TABLE 6—*Day of aurora after spots cross central meridian of Sun*

Distance from center	Days after −5	−4	−3	−2	−1	0
0° to 15°	3	1	4	4	6	3
16 to 30	1	1	0	0	5	1
31 to 45	0	1	1	1	1	0
Sum	4	3	5	5	12	4

Table 6 shows that most auroras occur about one day after a sunspot, or group of spots, crosses the central meridian. But since the aurora occurs on the night following the solar observation a half-day must be added, so that the spots are in the average about 20° west of the center of the Sun. However, there is considerable scatter in the position of the spots.

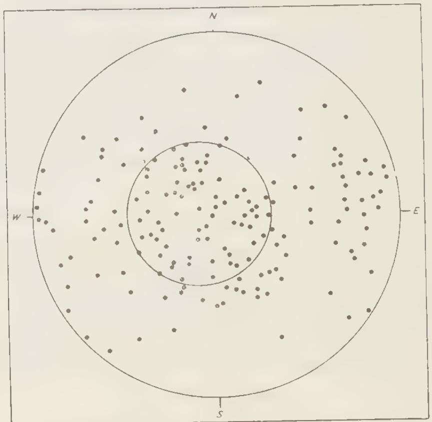


FIG. 1—POSITION OF SPOT-GROUPS ON THE SUN ON THE DAY PRECEDING THE AURORA, COUNTING ALL GROUPS, 1931-1939

Figure 1 shows the position of all spot-groups on the day preceding the date of the auroras from 1931 to 1939. The position of each group of spots is shown by a small circle. These positions were derived from my own drawings. If the spot-groups were evenly distributed over the Sun they would, owing to perspective, appear more crowded on the outer edge of a diagram like Figure 1 and more widely separated near the center. The data of the auroras observed at Ithaca, New York, from January 1938 to April 1939 were included in order to increase the mass of data. In a circle centered about 7° to the west of the center of the Sun's disk the spots show a condensation which, however, is not marked. This lack of concentration in a small area suggests the existence of another variable which may be the amount of heated matter surrounding the spots and emitting electrified particles or radiation-waves of high frequency.

Another factor of importance is that the equator of the Sun is inclined about 7° to the Earth's equator, so that in winter and spring the southern zone of spots is tilted more in the direction of the Earth while in summer and autumn the northern zone of spots are more in the Earth's direction. Since the larger number of spots accompanying auroras pass within 15° of the center of the Sun's disk, it is to be inferred that more spots in southern latitudes will accompany auroras in winter and spring and more spots in northern latitudes in summer and autumn.

All spots passing within 15° of the center of the Sun's disk for the day of the aurora and for the three days preceding the aurora are tabulated in Table 7.

TABLE 7—*Spots crossing 0° to 15° of the Sun's center preceding auroras**

Latitude	South	North
January to May	31	14
July to November	9	24

Professor A. E. Douglass[4] has advanced the view that the semi-annual periods of the magnetic and other electric manifestations on the Earth associated with solar changes are due to the fact that the zone of spots in the southern hemisphere of the Sun is brought more nearly in line with the Earth in late summer and in autumn, thus causing a double annual period in their effects.

Still another conclusion must be drawn from the fact that both size and latitude are factors in the effects of sunspots, namely, that since the zone of sunspots continued to approach the equator after their maximum intensity there will be a lag in the maximum of auroras, magnetic storms, and radio influences behind the maximum of sunspots. This conclusion agrees with the results found by Chree, Fisk, and Stetson previously quoted.

[4]A. E. Douglass, Climatic cycles and tree growth, p. 78, Carnegie Inst. Pub. No. 289, Washington, 1936.

*A. L. Cortie (Mon. Not. R. Astr. Soc., 73, 52-60, 1913) first discussed the hypothesis that (*a*) the inclination of the Sun's axis might cause the semiannual variation in geomagnetic disturbance and that (*b*) southern spots and northern spots should be more efficient in producing magnetic disturbances about March 5 and about September 7, respectively. While the semiannual wave in activity is clear enough, direct evidence for the correlated idea (*b*) is still obscured by statistical fluctuations, even in the data (more extensive and more suitable for such studies) on geomagnetic activity (see Physics of the Earth, 8, pp. 52 and 397 ff., McGraw-Hill Book Co., New York, 1939). It is questioned whether the Table given by the author has any immediate bearing on this problem because the Sun's equator divides the concentric circle of 15° radius on the Sun's disk in such a manner that on the average in January to May only about one-third of this circular area is on the Sun's northern hemisphere while in July to November only one-third is on the southern hemisphere. The approximate ratios 1:2 for southern and northern spots as given in Table 7 would therefore be found even if *all* spots were considered and is apparently therefore not a peculiarity of the spots connected with the aurora.—*Ed.*

Canton, Massachusetts, December 1, 1939

LETTERS TO EDITOR

(See also page 97)

PROVISIONAL SUNSPOT-NUMBERS FOR OCTOBER TO DECEMBER, 1939

(Dependent alone on observation at Zürich Observatory)

Day	October	November	December
1	144[ad]	...[a]	54[d]
2	143[a]	E ...[ac?]	40
3	...	72	43
4	92[aa]	61	...
5	...	58[a]	...
6	...[ad]	62	M ...[c]
7	...	66[a]	23[a]
8	...[d]	E 37[c]	47[d]
9	77	E 40[c]	...
10	67	M 46[c]	...[d]
11	56	E ...[ac]	...
12	E ...[ac]	82	...
13	...[a]	...	...[a]
14	E 68[ac]	E 98[ac*]	...
15	E 73[c]	87[a]	...
16	68	111[d]	53[a]
17	79[a]	...	52[ad]
18	E 74[aca]	103[b]	61*
19	92[d]	M 75[c]	44[d]
20	95	50	...
21	...[a]	67[d]	46[d]
22	94[d]	65[a*]	47
23	...	62	35*
24	112[a]	E 61[c]	...
25	...[bd]	58	32[a*]
26	100[d]	...	37[a*]
27	...	M 62[ac]	...
28	64[a]	61	...
29	E 81[c]	43[a]	...
30	85	43	46[d]
31	...[a]		34
Means......	87.6	65.4	43.4
No. days....	19	24	16

Mean for quarter, October to December, 1939: 66.6 (59 days)
Mean for year 1939: 91.2 (293 days)

*At temporary station of observation, Chur.
[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

NIGHT-SKY LIGHT AND NOCTURNAL *E*-LAYER IONIZATION

By N. E. Bradbury and W. T. Sumerlin

Abstract—In accordance with the suggestion that the sporadic nocturnal *E*-layer ionization may be associated with variations in the luminosity of the night sky, a simultaneous investigation of both these phenomena has been carried out. The intensity of night-sky light was determined by means of a recording electrometer and photoelectric cell, measurements being made only after twilight and during such times as the Moon was below the horizon. At different times both a Kunz KH-cell and a CeO-cell were employed. The ionosphere was investigated simultaneously using a pulse-transmitter and photographically recording receiver operating at a frequency of 2.1 megacycles. The blue portion of the night-sky luminosity appears to increase after sunset to a maximum shortly after midnight with a subsequent slow fading. The light in the red region of the spectrum shows much greater fluctuations in intensity and is brightest after sunset and decreases continuously thereafter. Practically no correlation has been found between the intensity of the night-sky light and the character of the ionospheric reflection. Various possibilities may be suggested to explain this result.

Introduction

It is well known that during the daylight hours, the density of ionization in the *E*-region of the ionosphere follows closely that which would be predicted from the absorption of solar radiation. Moreover, the time of maximum density seems to be closely, if not exactly, coincident with the time of maximum solar altitude. This behavior, together with that observed during solar eclipses, has led to the assumption that a large portion, if not all, of the daylight *E*-layer is to be ascribed to the absorption of ultraviolet radiation from the Sun.

Such agreement between theory and observation is, however, far from realized in the case of the *E*-layer after sunset. In view of the probable pressures at the 100-km level, it would be expected that shortly after the removal of the ionizing source, attachment of electrons to free molecules or atoms would take place and within a comparatively short time the effective density of the layer would be so reduced that the reflection of a radio pulse of the usual frequencies would no longer take place. Such behavior is far from being observed. Instead there is frequently observed an *E*-layer after nightfall which appears and disappears in what appears to be a rather sporadic manner. If the monthly average of such observations is taken as has been published for Huancayo [see 1 of "References" at end of paper], no smooth decrease in density between sunset and sunrise takes place, but instead there appears to be a poorly defined maximum near midnight. Such an increase, if real, is difficult or impossible to explain on any reasonable theory of a recombination process. Accordingly, it appears that there must be a source of ionization effective at about the *E*-level which can operate during the night. Hulburt [2] has outlined several possible modes of explanation, but the exact cause of a nocturnal *E*-layer must still be regarded as uncertain.

It has been suggested [3] that there may be some connection between the nocturnal luminosity of the sky and the appearance of *E*-layer ionization after nightfall. The arguments which suggest such a correlation are partly as follows: (1) The radiation emitted by the night sky is similar, though not identical, with that of the polar aurora. The latter, presumably caused by the entry into the Earth's atmosphere of high-speed particles, is frequently associated with geomagnetic activity probably as a consequence of changes in the high-level ionization-density. (2) The polar aurora shows an intensity-distribution with height

which has a maximum near 100 km. This is sufficiently close to E-layer heights as to be at least suggestive. (3) Rayleigh and others have found that for certain spectral regions, the light of the night sky shows a maximum shortly after midnight. The increase in E-layer ionization density reported from Huancayo at about this time is at least a curious coincidence.

Although it must be admitted that a completely satisfactory explanation of the polar aurora has yet to be found, and that it is by no means certain that the general non-polar aurora or night-sky luminosity has the same or even similar origins, nevertheless, it has seemed worthwhile to investigate experimentally the possible correlation of these phenomena.

Apparatus

The intensity of the night-sky light was measured by the method suggested by Grandmontagne [4]. In this method, a photoelectric cell is exposed to the night sky and the current resulting from light falling on the cell flows through a high-resistance approximating 10^{10} ohms. An electrometer records the potential-drop across this resistance. In the present experiments, two cells were used at different times to investigate different portions of the night-sky spectrum. One of these was a potassium-hydride cell made by the late Dr. Kunz which has a sharp spectral sensitivity-peak at about $\lambda 4500$Å; the other a CeO-cell of commercial manufacture which is most sensitive in the red end of the spectrum. Both cells were exposed to that portion of the sky included in the 90° cone with vertical axis. A light-shield protected the cell from illumination due to any other sources. A shutter-mechanism was so arranged that the cell was exposed to the sky only during the hours between $20^h 30^m$ and $3^h 30^m$ and during such times as the Moon was below the horizon. This precaution was necessary in order to prevent damage to the cell from too great light-intensity. The deflection of the electrometer was recorded photographically in the usual manner. The entire apparatus was enclosed in a thermally insulated box whose interior temperature was kept constant and somewhat higher that the surroundings by means of a thermostatic control. A thin spherical glass shield protected the photoelectric cell from the outside atmosphere. In order to measure only the excess current due to the sky light, above that due to the normal dark-current of the cell, the shutter-mechanism was arranged to close for three minutes each hour, thus affording a regular check on the instrumental zero as well as a time-scale.

For the simultaneous study of the ionosphere a specially designed pulse-generator and a receiver were employed. The unit was operated at a constant frequency of 2.138 megacycles with an interval of eight minutes between pulses. The ground-wave and reflected pulse were received by a standard broadcast receiver operating a 3-inch oscillograph. The oscillograph-trace was then photographed on 35-mm film. Both transmitter and receiver were timed by means of small synchronous motors of the "Telechron" type thus permitting an accurate time-scale to be established. The photographed oscillograph-trace could then be used to determine the presence or absence of an E-layer, the presence or absence of F-reflections, and the total fading out of all reflections. While such a method of study unfortunately leaves undetermined the critical

frequency, it nevertheless has the advantage of simplicity and practicality.

The ionosphere-transmitter and receiver were located at Stanford University, California, while the night-sky recording mechanism was set up on the roof of the Lick Observatory at Mt. Hamilton, about 30 miles east. While such a separation is probably undesirable, nevertheless the removal of the night-sky study to a location free from scattered light from terrestrial sources was imperative. The Observatory is at an elevation of 4000 feet and quite free from disturbances of this character. Moreover, the records of the United States Weather Bureau observer at Mt. Hamilton made it easy to reject those data obtained during overcast or partially overcast nights. Because of the high frequency of clear nights at this season the observations were carried out during the months of June, July, and August, 1939.

Results

The average results of the night-sky light observations are shown in Figures 1 and 2 for the red and the blue portions of the spectrum. In obtaining these curves, only those data have been used which were taken on clear nights with the Moon below the horizon. No correction has been made for star-density or zodiacal light. In view of the wide angle of sky subtended and the short length of time during which observations could be made at night at this season, the light from these sources to the photocell remains essentially constant.

It will be seen that the blue portion of the spectrum increases in intensity after evening twilight, reaching a maximum shortly after midnight and decreasing slowly thereafter. This is in accord with the observations of Lord Rayleigh [5], who, using a rubidium-cell, found a maximum around midnight. A similar behavior for the green line of the night sky has been observed by several investigators [6, 7]. It must be pointed out, however, that other observations in different latitudes have given totally different results and it is highly possible that the phenomena are different for different stations.

In contrast with the blue end of the spectrum, the red portion, as measured with an unfiltered CeO-cell, shows a totally different average behavior. In this case, the intensity is a maximum after evening twilight and decreases continually until morning twilight. This is in contrast with some results of Grandmontagne [8] who found a maximum in the red light about five hours after sunset.

The character of the individual nightly records is very different in the two regions of the spectrum. In most cases the intensity of the blue light shows a regular and smooth change during the night, whereas the CeO-results show not only a marked random fluctuation during a given night, but also large changes from night to night. No attempt was made to relate the intensities in the two regions of the spectrum.

In interpreting the ionospheric records, the following rather arbitrary classification of reflections was employed: (1) Strong or definite *E*-layer reflection; (2) weak *E*-layer reflection; (3) weak *F*-layer reflection; (4) strong or definite *F*-layer reflection; and (5) absence of observable reflection from any layer. When these records were compared with those of the luminosity of the night sky, it was at once apparent that no direct

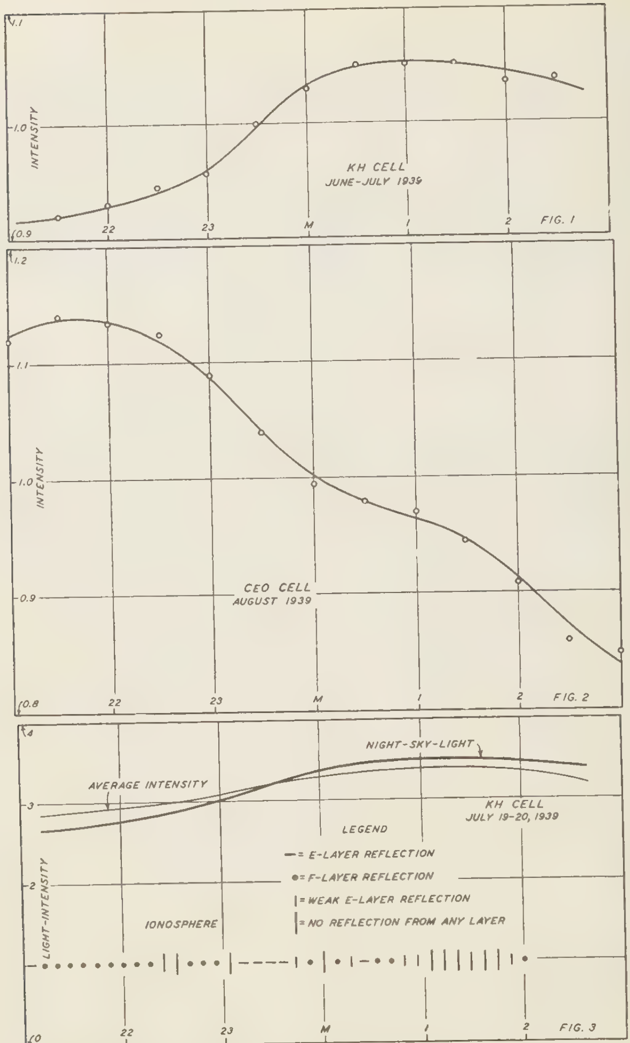


FIG. 1—NIGHT-SKY-LIGHT OBSERVATIONS FOR RED PORTION OF SPECTRUM
FIG. 2—NIGHT-SKY-LIGHT OBSERVATIONS FOR BLUE PORTION OF SPECTRUM
FIG. 3—TYPICAL RECORD SHOWING FLUCTUATIONS IN INTENSITY OF NIGHT-SKY-LIGHT ARE NOT DIRECTLY RELATED TO CHANGES IN IONOSPHERIC INTENSITY

correlation would appear. A typical record is shown in Figure 3 in which it is seen that the fluctuations in intensity of night-sky light are not related in any direct way to changes in the character of the ionospheric reflection. It is seen that increases or decreases in the light-intensity,

intensities above and below the hourly average intensity, and intensities above and below the overall average intensity are without apparent consistent relation to the changes in the character of the ionospheric reflection.

When all the data obtained were considered together, Tables 1 and 2 of percentage-occurrences resulted.

TABLE 1—*Percentage-occurrences of ionospheric reflections according to average sky-conditions*

Cell used	Condition of sky	Definite *E*-reflection	Definite *F*-reflection	No reflection
		per cent	*per cent*	*per cent*
CeO	Brighter than average	39±7	8±3	53±8
	Less bright than average	26±5	19±4	55±8
KH	Brighter than average	59±6	34±4	7±2
	Less bright than average	50±6	39±5	11±3

TABLE 2 -*Percentage-occurrences of ionospheric reflections according to average-for-time sky conditions*

Cell used	Condition of sky	Definite *E*-reflection	Definite *F*-reflection	No reflection
		per cent	*per cent*	*per cent*
CeO	Brighter than average for time	36±6	9±4	54±9
	Less bright than average for time	27±5	17±4	56±8
KH	Brighter than average for time	63±9	26±6	11±4
	Less bright than average for time	55±6	37±5	8±3

It is apparent from Tables 1 and 2 that in general there is no greater probability of a given ionospheric phenomenon occurring whether or not the brightness of the sky exceeds an average value. The only possible exception to this result is in the case of the appearance of *F*-layer reflection. This occurrence is always more probable when the sky is faintly luminous than when it is bright. The statistical error, however, is so great that even this result cannot be regarded with certainty. Furthermore, it is apparent that if a relationship exists between night-sky light and nocturnal low-level ionization, then this relationship must be greatly complicated by other factors.

Discussion

Although the largely negative results reported above seem fairly conclusive, certain reservations must be pointed out. In the first place, it is possible that nocturnal *E*-level ionization is not uniformly stratiform but consists of patches or clouds. If this is the case, it may well be that the brightness of the sky directly above the transmitter and receiver should be studied, rather than the general brightness of the sky over a large region. Such experiments as the present one may, by averaging over a large area, wipe out entirely the local variations to be

correlated with the ionization. Needless to say, an experiment of this type presents considerable difficulties arising from both the small intensity of light from a small solid angle as well as finding a satisfactory location for the transmitter and photocell.

In the second place, the time-constant of the electrometer photocell-circuit was of such a nature that light-intensity fluctuations of a period less than three minutes would be barely detectable on the record. If the existence of sporadic variations in ion-density in the region of the E-level have a time of existence of this same order, then many coincidences will be missed. However, taking sufficient data, even with what amounts to bad sampling, should ultimately bring to light a relationship if any exists.

Finally, it is by no means obvious just what region of the spectrum should be investigated. As noticed above, the different spectral regions have apparently greatly different behaviors, though it must be pointed out that, as indicated, the investigations were made in different months and the phenomena may well exhibit marked changes with time. Certainly the general character of the ionosphere was different at the two times as definitely indicated by Tables 1 and 2.

In conclusion the authors desire to express their thanks to Dr. W. H. Wright, Director of Lick Observatory, and to the members of the staff of the Observatory for their great kindness in making space available for this investigation. Particular thanks are due Dr. Gerald Kron for the loan of the special CeO-photocell used in this work.

References

[1] H. W. Wells and H. E. Stanton, Terr. Mag., **44**, 326-334 (1939).
[2] E. O. Hulburt, Phys. Rev., **55**, 639-645 (1939).
[3] N. E. Bradbury, Phys. Rev., **55**, 423 (1939).
[4] R. Grandmontagne, Paris, C.-R. Acad. sci., **204**, 337-340 (1937).
[5] Lord Rayleigh, Proc. R. Soc., A, **124**, 395 (1929).
[6] N. Dobrotin, I. Franck, and P. Cerenkov, C.-R. Acad. sci., USSR, **1**, 110 (1935).
[7] N. Wassmuth, V. Werzner, S. Tribilov, and S. Freivert, C.-R. Acad. sci., USSR, **19**, 405 (1938).
[8] G. Déjardin, Rev. Modern Phys., **8**, 1-21 (1937).

Stanford University,
Stanford University, California

ON THE EXISTENCE OF A BIANNUAL COMPONENT IN THE F_2-LAYER IONIZATION

By T. L. Eckersley

§1. *Introduction*—The problem of the mode of ionization of the ionosphere is of great physical interest. It is known that the ionosphere consists of three well-defined regions, the E-, F_1-, and F_2-layers, and that whereas the main features of the mechanism of the ionization of the E- and F_1-layers are known, there are many problems associated with the mode of ionization of the F_2-layer which remain as yet unsolved.

From the general nature of the diurnal variations in the ionic density in the E- and F_1-layers, as deduced from critical escape-frequencies measured at vertical incidence, it is obvious that the ionization is at least in part related to the Sun's radiation. It is now generally accepted that the E- and F_1-layers are mainly ionized by ultraviolet radiation from the Sun. There is some abnormal sporadic ionization which does not appear to be of solar origin, for instance, the ionization which is reponsible for the reflection of 7- to 10-meter waves to distances of 1000 km or so, and which does not apparently vary with the sunspot-cycle, and the sporadic ionization which persists throughout the long polar winter night. But the main E- and F_1-ionizations have been shown to obey the law deduced theoretically by Chapman for a region of the atmosphere ionized by a monochromatic radiation from the Sun, namely that the midday critical frequency should vary as $\cos^{1/4}\theta$, where θ is the zenithal angle of the Sun. The wave-lengths of the ionizing radiations and the precise molecular or atomic reactions involved are as yet unknown, as it would need a complete spectroscopic analysis in the ultraviolet region of O, N, O_2, and N_2 in their various excited and ionized states to determine them. Eclipse experiments on the accompanying changes of density during the optical eclipse also confirm the idea that the ionization of the E- and F_1-layers is mainly due to ultraviolet light from the Sun.

On the other hand the F_2-ionization not only varies greatly from day to day, but also it does not obey the $\cos^{1/4}\theta$-law at all closely and exhibits a number of marked anomalies. Thus, contrary to expectation, the midday ionization in the Northern Hemisphere is less at midsummer than at midwinter, whereas the $\cos^{1/4}\theta$-law implies that the ionization should be greater at midsummer when the zenithal angle of the Sun is less, as is found for the E- and F_1-layers. Again, at midsummer the density is often less at midday than it is at $10^{\mathrm{h}}\,00^{\mathrm{m}}$ or $18^{\mathrm{h}}\,00^{\mathrm{m}}$ local time, that is, instead of there being a midday maximum there is a midday drop in the density-curve. As the rate of recombination of ions may be much smaller in the F_2- than in the E-layer, the maximum density may occur appreciably after noon, but such a midday drop would not be expected on the simple Chapman theory in which the temperature, and therefore the scale-height of the atmosphere, is assumed to be constant throughout the layer.

It was suggested by Appleton that the density-reduction at midsummer was caused by an expansion of the atmosphere due to intense solar heating, which would be a maximum at midday and at midsummer. Owing to its distribution over a greater height in the expanded atmosphere, the ionization would have a smaller maximum value than in a contracted atmosphere, a result which is confirmed by detailed analysis,

according to which the maximum ionization varies inversely as the scale-height of the atmosphere, and hence, other things being constant, inversely as the absolute temperature.

To solve the problem of the mode of ionization of the F_2-layer, we need to analyze as completely as possible the variations of density in the F_2-layer, and this can only be done by making critical-frequency observations all over the world. At present no such complete survey is being made, but the National Bureau of Standards and the Carnegie Institution of Washington have earned the gratitude of radio workers by obtaining and publishing critical-frequency results respectively at Washington in the Northern Hemisphere, and at Watheroo in the Southern Hemisphere. The results refer mainly to midday, and only extend over a period of three years, but they are sufficient to indicate the major factors in F_2-ionization.

§2. *Description of the features of F_2-ionization*—The curves showing the characteristic run of the midday critical frequency f_0-values at Wash-

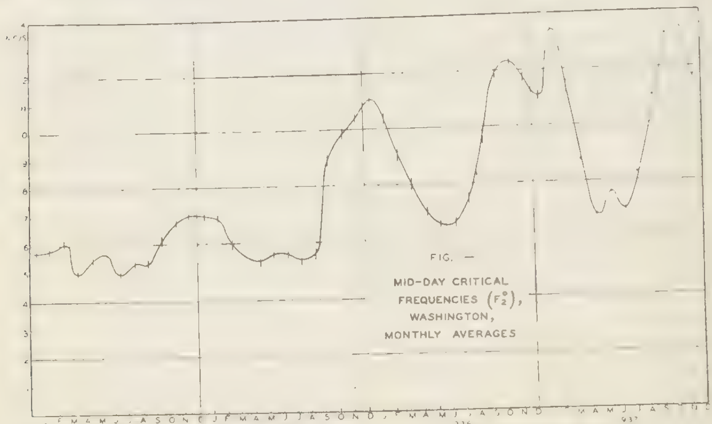


FIG. — MID-DAY CRITICAL FREQUENCIES (F_2^0), WASHINGTON, MONTHLY AVERAGES

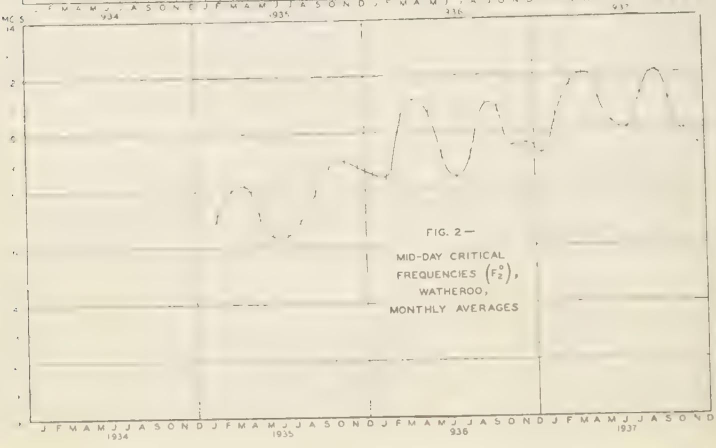
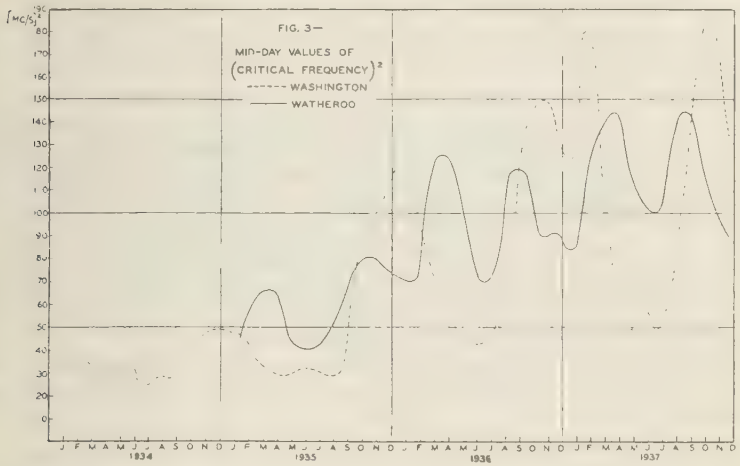


FIG. 2— MID-DAY CRITICAL FREQUENCIES (F_2^0), WATHEROO, MONTHLY AVERAGES

ington and Watheroo, respectively, are shown in Figures 1 and 2. The Washington curve extends over the years 1934 to 1937, and the Watheroo curve begins a year later in 1935. In Figure 3 these curves are shown



together for comparison, and expressed in terms of f_0^2 as a measure of the density. Now these curves have been subjected to a detailed analysis by Berkner and Wells [see 1 of "References" at end of paper], and they point out that even a casual inspection shows that the fluctuations in the Northern and Southern hemispheres are not similar, and that the deviations from the simple $\cos^{1/4}\theta$-law cannot be explained in terms of an expansion-effect alone.

This effect would be a seasonal one, being a maximum at midsummer in both hemispheres. If it alone were responsible for the behavior of the midday F_2-ionization, the density-changes throughout the year should follow the same course in the Southern as in the Northern Hemisphere, only the one curve would be shifted six months with respect to the other. Thus, disregarding the effect of second and higher harmonics, the seasonal fluctuations in the two hemispheres should be exactly out of phase.

We should expect that the density in the Southern Hemisphere should be less in December (midsummer) than in June (midwinter), but the curves show that there is a tendency for relatively high values to occur in December and low values in June in the Southern as well as in the Northern Hemisphere.* There appears, therefore, to be some extra effect which tends to keep the density high in December all over the world, and Berkner and Wells have attributed these world-wide high densities to an extra ionizing component which exhibits an annual variation with a maximum in December. This component they call an "in-phase" effect in contrast to the "out-of-phase" seasonal effect.

In support of this idea, we notice that the contrast between the

*When allowance is made for the secular change.

December maximum and the June minimum is much more marked in the Northern than in the Southern Hemisphere, as the seasonal effect happens to be in phase with the annual effect in the Northern Hemisphere, and therefore out of phase with it in the Southern Hemisphere. As the annual effect is comparable with the seasonal effect, the net result is to produce a much reduced contrast compared with the large contrast produced in the Northern Hemisphere by the additive effect of the two components.

In analyzing the curves into these two components, it is first necessary to remove the large secular effect associated with the sunspot-cycle which is obviously present in both curves. To obtain the curves representing the secular effect, the annual mean densities at Washington and Watheroo are taken to give a set of points through which the respective curves can be drawn. After removing the secular effect, it is assumed in resolving the curves into an annual and a seasonal effect, that the distance of Watheroo (latitude 30° 19′ south) from the equator is nearly enough equal to the distance of Washington (latitude 38° 55′ north) on the other side of the equator for differences in ionization due to the difference in latitude to be negligible.*

The detailed analysis carried out by Berkner and Wells may thus be summarized by saying that they resolve the total effect into three as follows:

(1) A very large secular change proportional to the sunspot-number
(2) A seasonal "out-of-phase" fluctuation which also increases slightly with the sunspot-number
(3) An annual "in-phase" component of roughly the same amplitude as the seasonal fluctuation which does not vary with the sunspot-number

As we have seen, the secular effect is obviously related to the Sun's activity and follows the sunspot-cycle, while the seasonal effect is probably a heating effect, as suggested by Appleton, which produces a reduction of density in the summer by expansion relative to the corresponding winter density. The cause of the annual effect is unknown. It may be solar, but it may possibly be sidereal, for example, a radiation from some particular part of the galaxy.

§3. *A proposed modified analysis of the curves*—It is to be noted that the inspiration for their analysis came from an inspection and comparison of the Washington and Watheroo curves. It was obvious from these that in the Northern Hemisphere two effects were combining to produce a big fluctuation, while in the Southern Hemisphere they were opposing to produce a smoothing effect. Their detailed analysis, as far as it goes, shows that the resolution of the curves into a secular, seasonal, and annual effect is very reasonable. But any such resolution cannot be unique or final, as it is possible mathematically to analyze the results in an infinity of ways according to the assumptions made regarding the components contributing to the ionization. In seeking to decide between possible alternatives, we must be guided by the plausibility of the assumptions

*This assumption is discussed by Berkner and Wells, and they show that the effect that is produced by the difference of latitude is partially counterbalanced by the effect produced by the ellipticity of the Earth's orbit, and that the resultant effect is very small.

made, and the extent to which the detailed features of the observations are explained by the analysis.

Now one of the most striking things about the critical-frequency results obtained at Washington, and also at Slough and Chelmsford in England, over a number of years, is that although the density throughout the winter months is considerably greater than the density during the summer months, there is not a single maximum of density at midwinter, but a pair of maxima with a small but definite drop between them. This drop occurs at midwinter and the peaks on either side are well out towards the equinoxes, as can be seen in Figure 1. This feature is so definite and so regular that it cannot be just a matter of chance, but it must have some real physical meaning. Moreover it is not a necessary consequence of the analysis given by Berkner and Wells, so that it was felt that a new analysis was justified which would take account of this feature and suggest a possible explanation of it.

The main purpose of this paper is therefore to present such a new analysis. Naturally, it proceeds along the same general lines as those indicated by Berkner and Wells, but it is modified by the inclusion of an extra component assumed for the purpose of explaining the double peak. The physical significance of such a component is then discussed.

The most obvious explanation of the double peak is to assume that there is also present a biannual component, that is, one which produces two maxima instead of one each year. These maxima would be separated by six months, and by assuming that they occur at or near the equinoxes, and that they are superimposed on an annual effect producing a maximum at midwinter, we shall obtain the observed result of two peaks displaced in from the equinoxes and disposed on either side of the midwinter solstice with a small drop in between at the solstice itself.

We take as the starting point of our detailed analysis the Washington and Watheroo curves given in Figures 1 and 2. In plotting the mean monthly values of the critical frequency, the probably errors are shown by extending the points into short lines reaching to the limits of the probable errors. The smooth curve is then taken through the points in such a way that it never goes outside the limits defined by these lines. In the quasi-stationary state, the total ionizing function is proportional to the square of the ionic density produced, and is therefore proportional to the fourth power of the critical frequency, assuming of course that the process by which the density tends to disappear is one of simple recombination. But actually it makes no fundamental difference to the results of the analysis if we work in terms of density, that is, of the square of the critical frequency, and as it is not known whether the F_2-region of the ionosphere is in a quasi-stationary state, and the exact process by which the ionic density disappears when the ionizing source is removed is still a matter of dispute, it seems most reasonable to adopt the simpler scheme of analyzing the density-curve as it stands.

For this reason the curves in which we are really interested as the basis of our analysis are given in Figure 3 in terms of the square of the critical frequency. We also assume that the effect due to the difference in the distances of Washington and Watheroo from the equator in their respective hemispheres is small, so that by taking the mean of the two curves the seasonal out-of-phase effects are eliminated, while these themselves are given by the difference of the two curves. This procedure

only fails to remove the second and higher harmonics of the seasonal effect. The seasonal effect so eliminated is shown in Figure 4, the curve referring to the phase of the effect in the Northern Hemisphere. It is

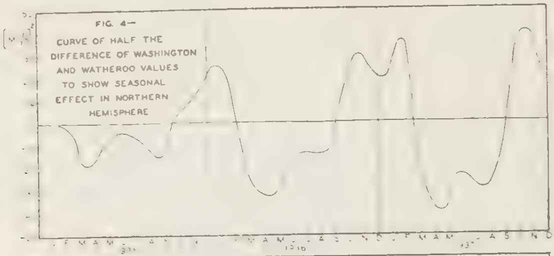


FIG. 4—CURVE OF HALF THE DIFFERENCE OF WASHINGTON AND WATHEROO VALUES TO SHOW SEASONAL EFFECT IN NORTHERN HEMISPHERE

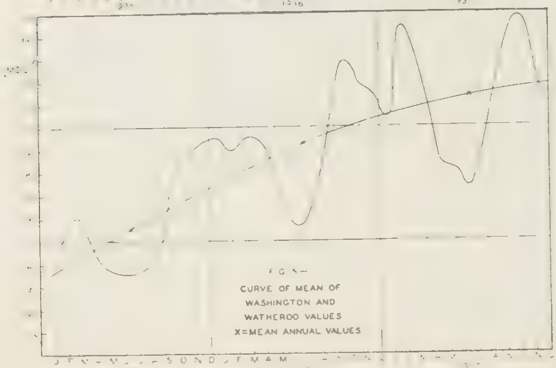


FIG. 5—CURVE OF MEAN OF WASHINGTON AND WATHEROO VALUES X=MEAN ANNUAL VALUES

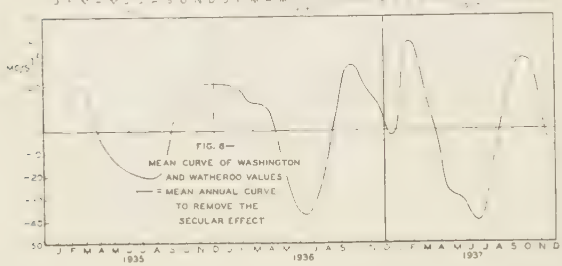


FIG. 6—MEAN CURVE OF WASHINGTON AND WATHEROO VALUES —— = MEAN ANNUAL CURVE TO REMOVE THE SECULAR EFFECT

seen to increase with the sunspot-activity towards 1937, but it may have reached a maximum at about May, 1937.

The mean curve from which the seasonal effect has been removed is shown in Figure 5, and it is this curve which has to be subjected to further detailed analysis. We begin by subtracting from it the mean annual curve, that is, the curve described above drawn through the mean annual values for the years over which the observations extend. This removes the major part of the secular effect. In subtracting this mean annual curve we can use either the curve obtained from the Washington results or the one from the Watheroo results, as they are found to be

practically the same. The resulting curve is shown in Figure 6, and it will be seen that the remaining fluctuations are not purely periodic but increase in amplitude as the sunspot-maximum is approached.

It is not possible to apply purely periodic analysis, but it is clear by inspection that the curve has a very marked algebraic minimum at, or close to, the summer solstice, and another less defined minimum at the winter solstice, with two maxima near the equinoxes but displaced in towards the winter solstice. As we have already suggested, this indicates the probable combined effect of an annual and a biannual effect, and we have now to decide how to resolve the curve into two such effects.

If the curve were simply the result of a biannual effect alone we should expect the winter minimum to reach the same value as the summer minimum. It is therefore reasonable to suppose that the amplitude of the annual effect is such as to cause the observed difference between the two minima, that is, the amplitude will be given by the differences between the winter and summer minima. Working on this supposition, Table 1 is constructed from the curve in Figure 6.

TABLE 1

Year	Minimum value	Differences
1934/5	Winter	19
		>40
1935	Summer	−21
		>42
1935/6	Winter	21
		>58
1936	Summer	−37
		>35
1936/7	Winter	− 2
		>38
1937	Summer	−40
		>32
1937/8	Winter	− 8

Average..........20.5×2

The differences do not show any systematic increase towards the sunspot-maximum conditions, and suggest that, as found by Berkner and Wells, the annual effect does not vary through the sunspot-cycle. We therefore take as the probable annual component a simple sine-curve of amplitude 20 as shown in Figure 7, with its maxima and minima at the winter and summer solstices, respectively.

Having determined the annual component in this way, the biannual component is obtained immediately by subtracting this annual component from the curve in Figure 6, giving the curve in Figure 8. The marked periodicity of this curve is at once obvious, and it indicates strongly that the resolution of the curve of Figure 6 into an annual and a biannual component in the way suggested is not merely an arbitrary mathematical device, but that it has a real physical significance. The curve in Figure 8 shows that the biannual component, unlike the annual component in Figure 7, does vary with the sunspot-activity, and actually it varies roughly in proportion to the mean sunspot-number.

Before discussing the possible cause of these effects, it should be

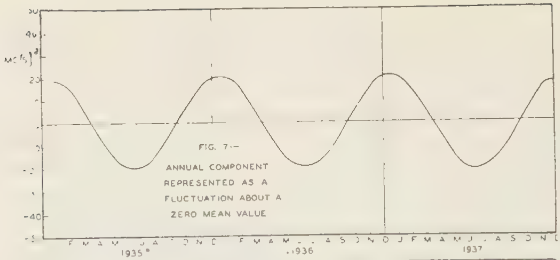


FIG. 7.—ANNUAL COMPONENT REPRESENTED AS A FLUCTUATION ABOUT A ZERO MEAN VALUE

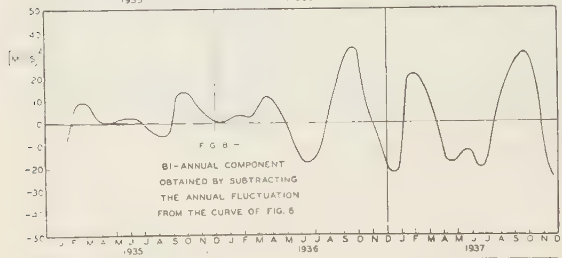


FIG. 8—BI-ANNUAL COMPONENT OBTAINED BY SUBTRACTING THE ANNUAL FLUCTUATION FROM THE CURVE OF FIG. 6

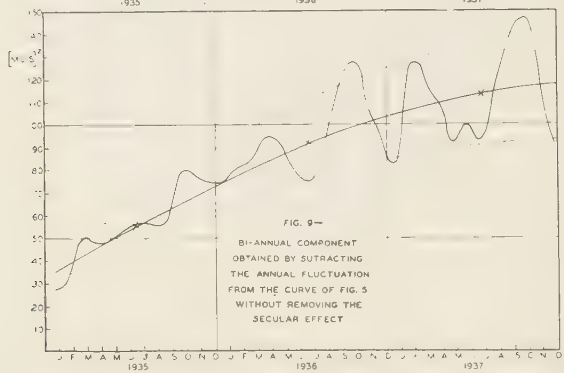


FIG. 9—BI-ANNUAL COMPONENT OBTAINED BY SUTRACTING THE ANNUAL FLUCTUATION FROM THE CURVE OF FIG. 5 WITHOUT REMOVING THE SECULAR EFFECT

pointed out that the resolution of the original curve in Figure 5, where the seasonal effect has already been removed, can be effected in a slightly different way by leaving the secular effect in and removing the annual effect. This will leave the biannual effect superimposed upon the main secular effect as in Figure 9, which shows rather more strikingly than Figure 8 the increase of the biannual effect with the sunspot-number. Strictly speaking these alternative ways of analyzing the curves, according to the order in which we make the resolution, are only equivalent when the effects produced by the components are additive and are represented in our curves by quantities which vary linearly with the ionization. But as we have stated above, the fundamental results of the analysis into an annual and biannual component do not depend upon the precise form of the function chosen, and our choice of the square of the critical frequency, as being proportional to the ionic density, proves to be reason-

able when the curves are subjected to analysis in the manner described above.

The alternative method of representing the biannual effect with the secular effect included emphasizes the point that in our analysis we do not determine the absolute values of the annual and biannual components but only the fluctuations of these components. Thus we do not mean, for instance, that the annual component represented in Figure 7 is actually producing a negative effect at the minima, but that it is subject to a fluctuation of this amount, and the amplitude of this fluctuation remains constant throughout the sunspot-cycle. But on the assumption that the minima of the curve in Figure 7 do actually represent small positive effects, we can get an idea of the limits within which the mean value of the annual component must lie. In order to make the minima in Figure 7 have positive values, we must raise the curve by an amount at least equal to the amplitude-value of 20, and assuming the mean value is also constant and independent of the sunspot-cycle, we have to subtract it from the curve in Figure 9 to give the actual biannual effect, which itself must always be positive. The amount which we can thus subtract is limited by the small value of the curve in Figure 9 at the beginning of 1935, which was near to the sunspot-minimum conditions, and it is obvious that the limit is about 25.

We can thus say that the biannual effect is very small at the sunspot-minimum, the fluctuations being correspondingly small, while the mean value and the amplitude of the fluctuations both increase rapidly with the sunspot-cycle, to a maximum fluctuation of ± 30 about a mean value of about 100. The annual effect has a mean value of say **20 to 25** with a fluctuation of about ± 20, so that the contrast between the maxima and minima is large.

§4. *Possible physical causes of the component effects*—We have seen that, whereas the annual effect is apparently independent of the Sun's activity, the biannual effect depends markedly upon the sunspot-cycle. It is interesting to note that there is also a biannual effect in magnetic-storm activity, which may also be associated with the Sun. This effect has been analyzed by Bartels [2], who considers that the fluctuation is physically significant.

As to the cause of the biannual fluctuation of F_2-ionization, it can

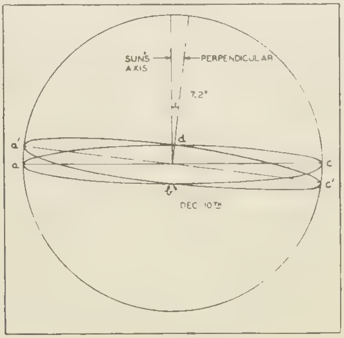


FIG. 10

only be the subject of speculation. A possible explanation is that it depends upon the distribution with solar latitude of the ultraviolet radiation from the Sun*. If in Figure 10, referred to the center of the Sun at 0, *abcd* is the equatorial plane of the Sun, and *a'bc'd* is the ecliptic, that is, the plane of the Earth's orbit, cutting *abcd* at *b* and *d;* the inclination of the Sun's axis to the ecliptic is 7°.2, and the Earth is at the point *b* on December 10. Assuming that the F_2-ionization is at least partly produced by the Sun's ultraviolet radiation, which according to Saha [3] is greatly in excess of the black-body radiation, we should expect the greatest ionization when the line joining the Earth to the Sun's center passes closest to the disturbed regions of the Sun. Now from sunspot, magnetic, and chromospheric evidence, it appears that the most active areas of emission from the Sun are associated with the regions of the Sun's latitude most occupied by sunspots which range from 7° to 20° north or south as the sunspot-cycle varies from maximum to minimum. In these circumstances, the line joining the Sun's center and the Earth is closest to the disturbed regions on March 5 and September 7. Actually the biannual fluctuation, as analyzed from the results, has mean maxima at March 6, and September 27.

The magnetic biannual fluctuation has been attributed to a similar cause, but Bartels claims that the phase is not associated with the maximum inclination of the Sun's axis to the Earth-Sun direction, but with the actual equinox. As there is only a difference of 15 days, it would appear that the phase is not well enough determined to allow of a certain discrimination between them, and the experimental results might be equally well interpreted in terms of either. Physically the maximum should not necessarily coincide with the theoretical maximum inclination, as the disturbed areas are not entirely regularly spaced on the Sun. But whatever the exact origin of the effect, there does not seem to be any doubt of its existence.

In putting forward possible explanations of the results of our analysis, we must remember that so far the analysis only applies to Washington and Watheroo, and thus we do not know how the various effects vary with latitude. Also the results only refer to midday, where, since (dN/dt) is nearly zero, the density N can most nearly be taken as a measure of the ionizing agency. At other times of day the density is more or less controlled by the previous history, especially in the F_2-layer where the rate of recombination is relatively slow.

At midnight, however, although the conditions are not steady, (dN/dt) is small in general, so that it might be possible to supplement our knowledge by analyzing the available midnight values. This should be especially valuable in respect of the annual effect, which does not apparently vary with the sunspot-activity, and which is therefore possibly due to some source outside the solar system. If the annual effect is caused by ultraviolet radiation from the Sun, it should only occur in the daytime, but if, on the other hand, it is due to a corpuscular sidereal radiation from a well-defined direction in space, the maximum effect will occur at a given sidereal time, and not at a given solar time. Thus, if it is a maximum at midday, in December and January (midwinter, Northern Hemisphere), it should also be a maximum at midnight in June and July (midsummer, Northern Hemisphere).

*This explanation has recently been proposed by Appleton; *cf.* Nature, **144**, 151-152 (1939).

Fortunately some results of midnight observations of the F_2 critical frequency made at Tokyo [4] have been published, and they are reproduced in Figure 11 together with a curve of midnight values constructed from the data published by the National Bureau of Standards at Washington.

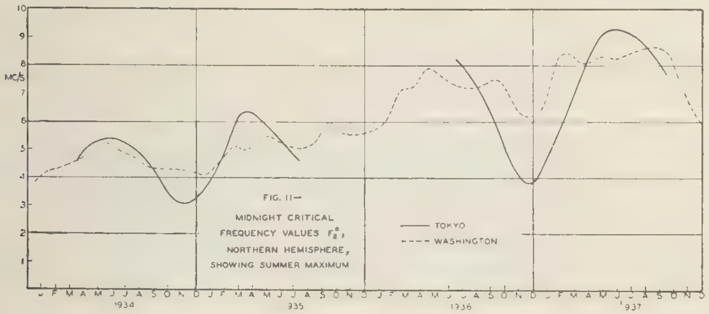


FIG. 11—MIDNIGHT CRITICAL FREQUENCY VALUES F_2^0, NORTHERN HEMISPHERE, SHOWING SUMMER MAXIMUM

These curves show very clearly that there is a midnight maximum in June and July, at least in the Northern Hemisphere, and this result is supported by measurements made at Slough and at Chelmsford. This evidence is very far from conclusive, since it is necessary to have similar observations made in the Southern Hemisphere as a check, and so far only a few are available.

It is, perhaps, significant to note that the midnight amplitude of the annual component is of the same order as the amplitude of the annual component already found. This is, of course, not the only way of accounting for the pronounced high midnight values at summer in the Northern Hemisphere where it might otherwise be supposed to be small, since the initial value of N at sunset is small compared with, for instance, the winter value. It is possible that some process by which energy is stored during the day, for example, by dissociation, and liberated at night by recombination to cause fresh ionization, may be responsible for the midnight maximum.

There is another fact which may be of interest in connection with the annual effect, namely its relation to the Jansky noise [5] which is itself an annual effect. The latter effect is a maximum at 18^h right ascension, and therefore also corresponds to a maximum at midday in midwinter for the Northern Hemisphere. This Jansky noise has been shown to come from directions associated with the Milky Way or Galaxy, the maximum occurring from the direction of the nearest part of the Galaxy, the Sun being eccentrically placed in this system.

It is possible therefore that the annual effect in the F_2-ionization may similarly be identified with a radiation from the Galaxy which has a maximum effect, corresponding to the nearest part of the Galaxy, at midnight in summer, and at midday in winter for the Northern Hemisphere.

§5. *Summary*—Apart from speculations, we may say that the midday densities at Washington and Watheroo can be expressed very clearly as the sum of two main parts:

(*a*) A secular effect proportional to the Wulf sunspot-number
(*b*) Fluctuation-effects

These latter can be analyzed into three parts:

(1) A seasonal effect dependent on the sunspot-number
(2) A biannual effect proportional to the sunspot-number
(3) An annual effect independent of the sunspot-number

It is suggested that the biannual effect is associated with the distribution of sunspots on the surface of the Sun, the sunspots being grouped about two latitudes north and south of the Sun's equator and the Sun's axis being tilted towards the ecliptic; while the annual effect may be produced by extra-terrestrial radiation originating in the Galaxy.

Further work is required to see how these effects vary diurnally and with latitude, and possibly magnetic latitude. The results of such work will give hints as to the origin and nature of the three components, which will confirm or modify the tentative explanations put forward as a deduction from the analysis of the present limited results available, but there does not seem to be any reasonable doubt that the three components really exist, whatever further light may be thrown on their nature and origin.

References

[1] L. V. Berkner and H. W. Wells, Terr. Mag., **43**, 15-36 (1938).
[2] J. Bartels, Terr. Mag., **37**, 1-52 (1932).
[3] M. N. Saha, Proc. R. Soc., A, **160**, 155-173 (1937).
[4] K. Maeda, T. Tukada, T. Kamoshida, Rep. Radio Res. Japan, **7**, 109-119 (1937).
[5] K. G. Jansky, Proc. Inst. Radio Eng., **21**, 1387-1398 (1933); **23**, 1158-1163 (1935).

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RESEARCH AND DEVELOPMENT DEPARTMENT,
Chelmsford, England, October 5, 1939

MEASUREMENTS OF F_2-REGION IONIZATION OVER NEW ZEALAND

F. W. G. WHITE, C. J. BANWELL, AND G. A. PEDDIE

(1) *Introduction*—Compared with the other two main ionized regions of the upper atmosphere (E- and F_1-regions) the highest and most richly ionized region (F_2) presents theoretical problems which can be discussed adequately only when data collected in many different places of the Earth's surface can be examined simultaneously. The situation is similar to that of terrestrial magnetism in that the observations at one observatory cannot yield sufficient data upon which a theoretical discussion may be based.

Amongst the many observations which can be made with wireless waves reflected from the F_2-region the most fundamental are concerned with the measurement of the maximum charge-density of this region. In view of the apparently anomalous behavior of this region it is of interest to investigate firstly the diurnal and secondly the seasonal variation of the maximum charge-density of the region. Thirdly the wide fluctuations of this quantity which occur from day to day are of interest since they appear to be intimately connected with other geophysical occurrences.

In this paper data collected in New Zealand on each of these points are presented. A preliminary account of some of the early measurements has already been given by two of us [see 1 of "References" at end of paper]. Here data covering a much extended period are presented and also the observations made at another Station (Wellington) are presented for the first time.

The emitting and receiving equipment used was installed at Canterbury University College, Christchurch (latitude 43° 32′ south, longitude 172° 37′ east), and at Victoria University College, Wellington (latitude 41° 18′ south, longitude 174° 46′ east). The distance between these stations is 310 km. At each station the equipment was arranged for the Breit and Tuve group-retardation technique and was manually controlled. At the former station the emitter and receiver were in the same room so that a single operator could control both. The emitter was arranged to change its frequency continuously so that, with a manual control of the receiver, photographic records of the relationship between the equivalent height of reflection of the waves and their frequency could be obtained. Records of this type were obtained regularly at noon but at other times of the day the critical frequency was measured by direct observation of the oscillograph. At the second station the emitter and receiver were about five km apart. Each was manually controlled and the same method of observing the critical frequency was employed. The results presented here represent all those collected by the use of the manually controlled apparatus; automatic apparatus with photographic registration has now been installed at Christchurch and will be used in the future.

(2) *Experimental observations: General*—At the Christchurch station the program of observations was as follows. On each day, excluding Sundays, hourly measurements of the critical frequency of the F_2-region ($f^{\circ}_{F_2}$) were made. It was usually possible to carry out this measurement only at noon on Sundays but on other days the measurements were made during the period from 9^h until 18^h. For convenience the readings were

taken on the hour of local time whether New Zealand mean time (NZMT) or New Zealand summer time (NZST) prevailed. A half-hour difference exists between these times, NZMT being exactly 11 hours 30 minutes ahead of GMT and NZST being exactly 12 hours ahead of GMT. This is indicated in the tables of results and has been allowed for in the graphical presentation of results. For various reasons data for some days were not obtained; the more recent data are better than the earlier data in this respect.

In addition to the above the period of observations was extended to 34 hours (from 9^h on one day until 18^h on the following day) during the International days. In this way samples of the complete diurnal variation were obtained.

At the Wellington station the F_2-readings were confined to measurements of the critical frequency at noon. This measurement was not made on all days but sufficient readings are available to give a reliable monthly average. The measurement was made always at noon NZMT.

The period covered by these observations is from October, 1937, until April, 1939.

Diurnal variation—In terms of the observations the diurnal variation of the critical frequency ($f°_{F_2}$) can be exhibited by the average variation from 9^h until 18^h and also by examples of the variation which occurerd on certain days for which the 34-hour series of observations are available. For the former the monthly average values are given in Table 1. In the last column of this Table the number of days upon which readings were taken is shown. It is considered that in each month there are sufficient values to give a reliable monthly average value. In Figures 1*A*, 1*B*, and 1*C* these results are exhibited in graphical form.

In Figures 2*A*, 2*B*, and 2*C* the values for certain days throughout the year for which the extended series of observations are available

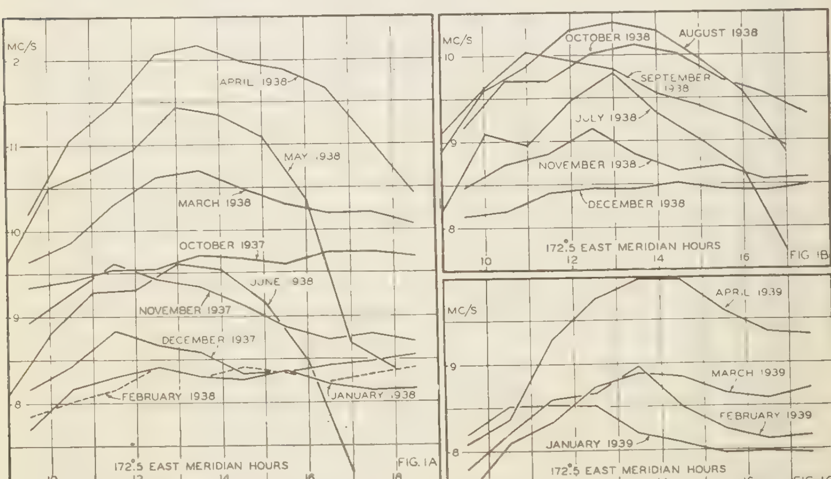


FIG. 1—DIURNAL VARIATION OF $f°_{F_2}$.

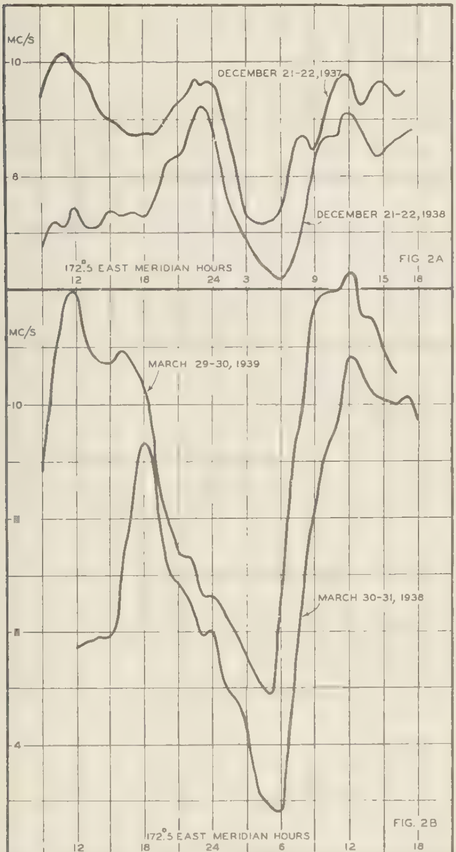


FIG 2A & B—DIURNAL VARIATION OF $f^\circ_{F_2}$ FOR 24 HOURS

are shown in graphical form. These Figures do not represent all the material available but have been chosen to represent as nearly as possible the diurnal variation during the four seasons. It must be remembered, however, that the large fluctuations in the level of $f^\circ_{F_2}$, which occur from day to day, may cause the diurnal curves for individual days to differ markedly.

During the long daylight hours in summer the average level of $f^\circ_{F_2}$ tends to be nearly constant. On some occasions a definite morning and afternoon maximum such as has been described by Appleton [2] occurs, but more often the variations are irregular. On December 21-22, 1937 (Fig. 2*A*), for instance, a very definite maximum occurred at $10^h\,30^m$ NZMT followed by a pronounced minimum at $16^h\,30^m$ and a second maximum at $22^h\,00^m$. This is, however, the only occasion upon

which this phenomenon was observed in a marked form. The curves of monthly averages of $f^{\circ}_{F_2}$ show that there was a tendency for a slight maximum to occur at $10^{h}\ 30^{m}$ during November and December, 1937, but this was entirely absent in December, 1938, and had moved to $11^{h}\ 30^{m}$ in November, 1938. Although there is no doubt that high values, approximately the same as the daylight average values, are maintained until about midnight in summer, no pronounced morning and afternoon maxima occur regularly in these latitudes.

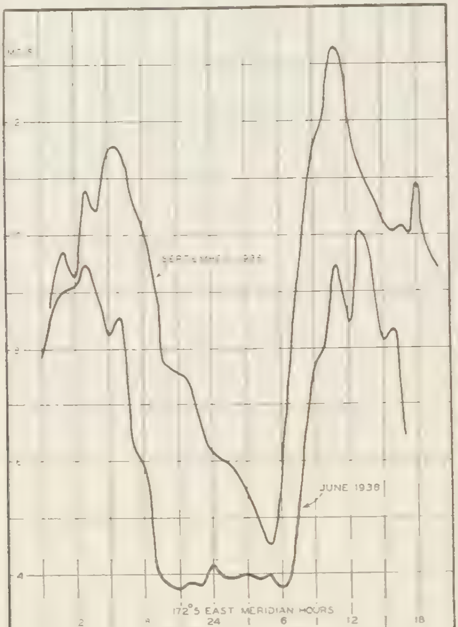


FIG 2C—DIURNAL VARIATION OF $f^{\circ}_{F_2}$ FOR 24 HOURS

Annual variation -In describing the annual variation of the F_2-region critical frequency at an observatory it is customary to do so in terms of the monthly mean values of this quantity at noon. During the daylight hours of a particular day the values of $f^{\circ}_{F_2}$ are subject to fluctuations which may be of the order of one mc/sec. The reading at noon may not be the maximum value for the day and moreover after taking the monthly means the same is true. Nevertheless the noon value may be used to indicate the level attained by $f^{\circ}_{F_2}$ for the day for it will indicate whether the value on a given day is high or low. On some occasions, particularly disturbed days associated with magnetic activity it is certain that a finer measure of the level of $f^{\circ}_{F_2}$ should be chosen.

Since, however, it is the purpose of the annual curve to indicate the general features of the variation of ionization throughout the year

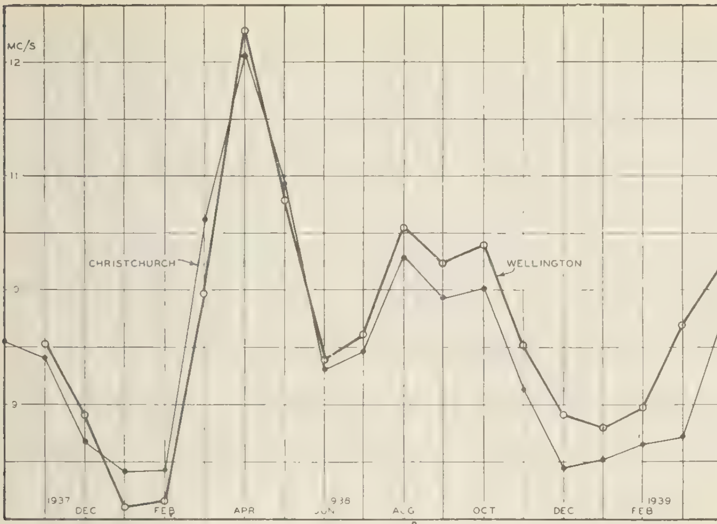


FIG 3—MONTHLY AVERAGES OF NOON VALUE OF $f^{\circ}_{F_2}$, CHRISTCHURCH AND WELLINGTON

there is no doubt that the monthly mean values of the noon critical frequency are sufficient for this purpose.

For Christchurch the monthly means of $f^{\circ}_{F_2}$ are shown in Table 1. Although some of the values have been taken half an hour later than others, in view of what has been said above this is neglected. The annual variation obtained with interpolated values during summer differs very little from that obtained when this half-hour difference is neglected.

TABLE 1—*Monthly means of $f^{\circ}_{F_2}$ in mc/sec at Wellington, New Zealand*

Month	Noon (NZMT) average value for Wellington	Hours										No. readings during month
		9	10	11	12	13	14	15	16	17	18	
1937												
Oct.	.....	9.34	9.41	9.55	9.55	9.70	9.67	9.60	9.74	9.74	9.68	19
Nov.	9.53	8.93	9.27	9.61	9.42	9.33	9.13	8.86	8.72	8.78	8.70	20
Dec.	8.91	8.16	8.44	8.84	8.67	8.58	8.34	8.36	8.43	8.47	8.55	25
1938												
Jan.	8.10	7.70	8.16	8.30	8.41	8.30	8.26	8.36	8.22	8.13	8.16	19
Feb.	8.16	7.85	8.02	8.15	8.42	8.30	8.41	8.38	8.23	8.32	8.40	23
Mar.	9.97	9.64	9.86	10.30	10.62	10.70	10.49	10.31	10.20	10.21	10.07	29
Apr.	12.27	10.19	11.05	11.46	12.06	12.16	11.98	11.88	11.64	11.05	10.44	29
May	10.79	9.62	10.50	10.70	10.94	11.44	11.35	11.09	10.35	8.69	8.05	26
June	9.38	8.09	8.81	9.28	9.31	9.61	9.54	9.16	8.49	7.17	6.46	30
July	9.61	8.19	9.08	8.95	9.47	9.79	9.32	9.01	8.66	7.71		30
Aug.	10.55	8.88	9.60	9.88	10.29	10.38	10.28	9.96	9.59	8.86		29
Sep.	10.23	9.09	9.62	10.04	9.93	9.84	9.55	9.40	9.20	8.94		29
Oct.	10.40	9.15	9.71	9.70	10.01	10.12	10.01	9.72	9.55	9.31		31
Nov.	9.52	8.46	8.74	8.85	9.13	8.84	8.65	8.71	8.55	8.57		25
Dec.	8.91	8.13	8.17	8.40	8.45	8.45	8.51	8.44	8.42	8.48		29
1939												
Jan.	8.80	8.18	8.51	8.52	8.51	8.19	8.07	7.96	7.96	7.95		29
Feb.	8.98	7.78	8.21	8.59	8.66	8.96	8.49	8.24	8.12	8.16		26
Mar.	9.70	7.50	8.08	8.32	8.72	8.88	8.84	8.65	8.58	8.70	8.86	30
Apr.	10.24	8.07	8.86	9.28	9.75	9.98	9.97	9.60	9.36	9.32	9.00	28

The monthly average values of $f°_{F_2}$ obtained at Wellington are shown in Table 1. The monthly average values for both Christchurch and Wellington are shown graphically in Figure 3. These results show that during summer and winter of the Southern Hemisphere the maximum of ionic density of F_2-region is at a minimum. A large maximum occurred in April, 1938, and another maximum between August and October, 1938. An examination of Figure 4 will show that the daily values during September, 1938, were very variable indeed; this may be connected with

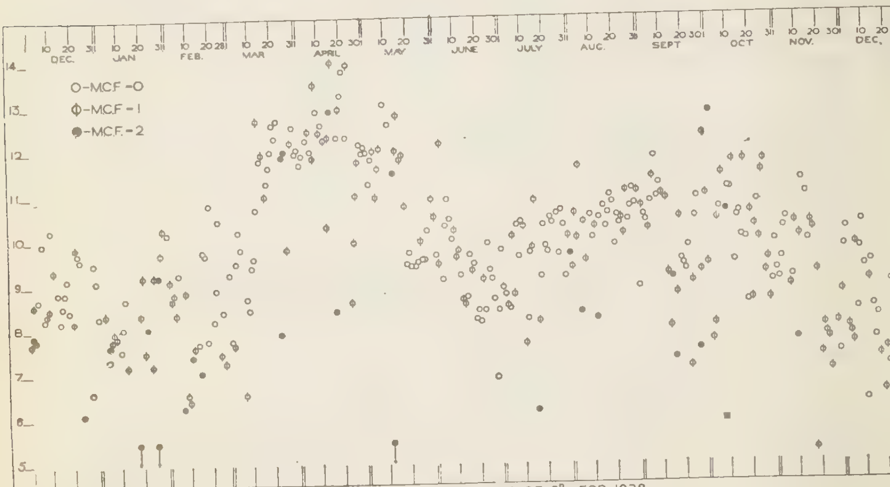


FIG. 4—DAILY NOON VALUES OF $f°_{F_2}$ FOR 1938

the September maximum in magnetic activity although, from an examination of the magnetic data available, September does not appear to have been very much more disturbed than October. The abnormally low values during September undoubtedly cause the small minimum in that month.

Comparing Christchurch and Wellington there is very good general agreement although there is a marked tendency for the Christchurch values to become smaller than those for Wellington. Since Wellington has a smaller latitude than Christchurch a smaller value at the latter place is perhaps to be expected, in a period of decreasing solar activity.

Day-to-day fluctuations—It is characteristic of the F_2-region that the level of ionization attained during the daylight hours fluctuates considerably from day to day. In order to illustrate this the noon values of $f°_{F_2}$ are again taken to be indicative of the general level for daylight conditions and the values for individual days for the year December 1937 to December 1938 are shown in Figure 4. Since there is certainly a tendency for part at least of the fluctuation to be correlated with magnetic activity the magnetic conditions at Christchurch are indicated in a general way in plotting these results. We are indebted to the Magnetic Observatory, Christchurch, for character-figures for the 24 hours immediately preceding

local noon. The figures (0, 1, 2) are indicated by typical signs in plotting the noon values.

A similar set of results for the Wellington station is not shown because the day-to-day fluctuations at Wellington are in general similar to those at Christchurch. Nevertheless there are some occasions upon which the Christchurch and Wellington values differ widely. To make absolutely sure that a significant difference does occur the hourly values at Christchurch were examined and days on which an hour-to-hour variation of the order of magnitude of the difference between the readings at Christchurch and Wellington occurred were excluded. This eliminates an apparent difference due to the fact that the Christchurch and Wellington readings were not simultaneous. After this had been done it was found that there was a significant difference on 31 occasions during 1938. This does not appear to be associated with magnetic activity for during a disturbed period the well-known fall in $f^\circ_{F_2}$ which occurs at such times is often experienced at both stations. Of these 31 occasions 14 are associated with magnetically quiet days, 13 with moderately disturbed days and only four with very disturbed days. It is evident that an explanation of this difference must be looked for in some other geophysical phenomenon.

(3) *Conclusion*---From an examination of the data for this period the following conclusions may be drawn:

(1) In these latitudes the diurnal curves did not show a marked morning and afternoon maximum in the values of $f^\circ_{F_2}$. In summer the daylight level of this quantity was maintained until well after sunset.

(2) The annual variation showed a pronounced minimum in the summer months and in the winter months. The maxima in $f^\circ_{F_2}$ occurred in April, 1938, and in September, 1938. The April maximum was higher than that in September. The annual curve was similar in form to that found at other stations in the Southern Hemisphere but there appears to be no regular variation with latitude.

(3) The day-to-day fluctuations in $f^\circ_{F_2}$ are found to be similar at Christchurch and Wellington on the majority of days; on certain days, however, there is a marked difference in $f^\circ_{F_2}$ at these two stations. The cause of this difference is at present unknown but it is evidently not connected with magnetic activity for such activity affects both stations similarly.

(4) *Acknowledgment*- The work described in this paper forms part of the research program of the Radio Research Committee of the New Zealand Department of Scientific and Industrial Research.

References

[1] F. W. G. White and C. J. Banwell, Proc. General Assembly, Internat. Sci. Radio Union, Rome, **5**, 75-84 (1938).
[2] E. V. Appleton and R. Naismith, Proc. Roy. Soc., **A**, **150**, 685 708 (1935).
[3] W. C. Parkinson and L. S. Prior, Terr. Mag., **44**, 199-204 (1939).

Canterbury University College (F. W. G. W. and C. J. B.),
Victoria University College (G. A. P.),
Christchurch and Wellington, New Zealand

PRINCIPAL MAGNETIC STORMS

(See also pages 48 and 107)

Sitka Magnetic Observatory

October to December, 1939

(*Latitude 57° 03′.0 N., longitude 135° 20′.1 or $9^h\ 01^m.3$ W. of Gr.*)

October 3-4—A small disturbance began gradually at about $08^h\ 30^m$ GMT, October 3, and increased slowly during the first five hours. The conditions continued mildly disturbed until 15^h, October 4. Ranges: *D*, 126′; *H*, 1053 gammas; *Z*, 760 gammas.

October 6—A short period of disturbance occurred between 04^h and 11^h GMT, October 6. *H* increased steadily during the first period until $05^h\ 30^m$, then suddenly decreased 450 gammas during the next ten minutes. Thereafter the traces gradually returned to normal. Ranges: *D*, 102′; *H*, 585 gammas; *Z*, 500 gammas.

October 13-15—A small magnetic storm began abruptly at $02^h\ 05^m$ GMT, October 13, with a sharp motion discernible in all components. This started a rapid vibrating motion with gradually increasing values of horizontal and vertical intensities with maximum values at 07^h. The intensities then began a steady decrease with the minimum at about 19^h, October 13. A period of intense activity occurred from 07^h to 15^h, October 14. Thereafter the disturbance gradually subsided; the traces reached normal values by 13^h, October 15. The trace continued somewhat disturbed for several days. Ranges: *D*, 211′; *H*, 1405 gammas; *Z*, 1006 gammas.

November 13—A small disturbance began gradually at about 03^h GMT, November 13, with decreasing values of horizontal intensity. After 16^h the values gradually returned to normal. The disturbance ended about 20^h, November 13. Ranges: *D*, 140′; *H*, 867 gammas; *Z*, 775 gammas.

December 6-9—A period of moderately disturbed conditions began gradually at 20^h GMT, December 6. It continued until 20^h, December 9.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory

October to December, 1939

(*Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h\ 07^m.4$ W. of Gr.*)

October 3-4—A mild disturbance began gradually about 07^h GMT, October 3. It reached its peak between 02^h and 06^h, October 4, during which interval all three elements had their greatest ranges. Ranges: *D*, 63′; *H*, 211 gammas; *Z*, 203 gammas.

October 6—An interval of moderate activity occurred between 05^h and 11^h GMT, October 6. Ranges: *D*, 22′; *H*, 123 gammas; *Z*, 126 gammas.

October 13-19—A storm began at $02^h\ 05^m$ GMT, October 13. Until 19^h, October 13, it was of moderate intensity; then it increased in severity and was very active with large ranges between 22^h and 23^h, October 13. During the early hours of October 14 and October 15 the storm was again active. The field continued to be disturbed until October 19. Ranges: *D*, 82′; *H*, 357 gammas; *Z*, 557 gammas.

THE IONOSPHERE AT WATHEROO, WESTERN AUSTRALIA, JULY TO SEPTEMBER, 1939

By W. C. Parkinson and L. S. Prior

This report continues from those previously submitted[1]. Table 1 gives the mean hourly values of minimum virtual height and critical frequency for the ionospheric regions for each hour of the three months July, August, and September, 1939 and also includes mean hourly values of the lowest frequency recorded, f_{min}, when this frequency was higher than the lower limit of the frequency-sweep, 16.0 to 0.516 megacycles per second. It should be noted that after July 1939, the scaling of the E virtual height was discontinued. Figure 1 gives the data of Table 1 in graphical form. The 120° meridian standard times of sunrise and sunset are shown on the graphs by broken vertical lines, these times being for the middle day of the month involved.

Although the curves for the three months differ substantially in themselves it is of interest to note how closely they resemble, in general features, the curves for the corresponding months of 1938. The resemblance is most marked during August and September when the apparatus was working over the entire frequency-sweep.

[1]Terr. Mag., **44**, 199-204, 341-343, and 401-403 (1939).

Table 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory July to September, 1939*

120° east mean time	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
			July, 1939				
00	107		266	0.71		3.53	
01	109		262	0.66		3.60	
02	108		260	0.68		3.57	
03	107		254	0.69		3.59	
04	105		249	0.70		3.38	
05	106		247	0.74		2.99	
06	107		261	0.81		2.88	
07	102		245	1.61		4.78	0.50
08	98		237	2.52		7.34	0.78
09	97	232	247	2.99	4.34	8.38	0.79
10	94	226	256	3.24	4.55	8.98	0.83
11	93	228	266	3.37	4.74	9.26	0.85
12	94	226	263	3.46	4.84	9.34	0.90
13	93	222	271	3.43	4.78	9.17	0.86
14	94	224	278	3.35	4.72	9.40	0.81
15	94	231	259	3.14	4.41	9.26	0.76
16	94	239	244	2.73	3.95	9.16	0.73
17	99		231	2.00		8.68	0.68
18	105		218	1.19		7.10	0.53
19	105		226	0.94		5.19	
20	105		246	0.86		4.12	
21	105		260	0.80		3.62	
22	105		266	0.72		3.59	
23	108		269	0.68		3.52	

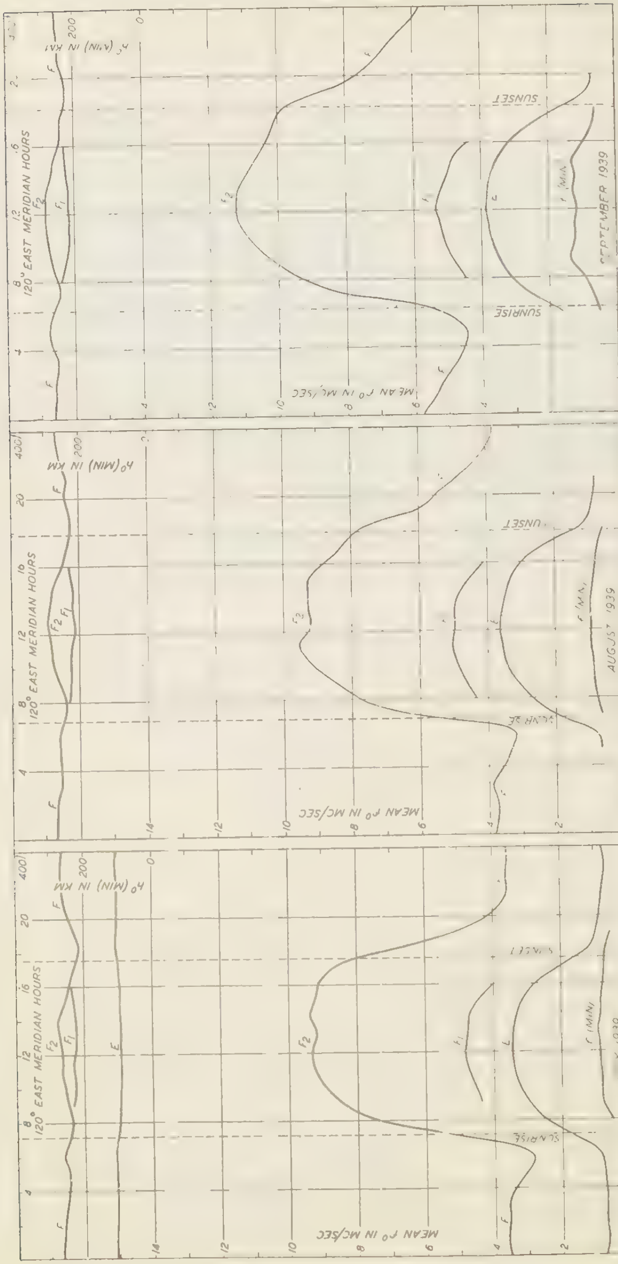


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, JULY, AUGUST, AND SEPTEMBER, 1939, WATHEROO, WESTERN AUSTRALIA

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory July to September, 1939*

120° east mean time	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
			August, 1939				
00			268			3.81	
01			267			3.76	
02			264			3.74	
03			252			3.88	
04			252			3.55	
05			255	0.69		3.32	
06			257	0.84		3.22	
07			242	2.06		5.90	0.64
08		230	238	2.71	4.35	7.70	0.78
09		226	255	3.12	4.61	8.50	0.86
10		226	273	3.44	4.89	9.11	0.89
11		222	280	3.54	5.02	9.53	0.94
12		215	286	3.61	4.94	9.27	0.93
13		217	290	3.57	4.99	9.23	0.97
14		217	283	3.48	4.87	9.28	0.92
15		220	271	3.30	4.53	9.29	0.84
16		229	248	2.94	4.09	8.77	0.79
17			239	2.28		8.30	0.71
18			227	1.24		7.74	0.56
19			227	0.90		6.12	
20			243	0.81		5.50	
21			237	0.78		4.89	
22			254			4.35	
23			264			3.96	
			September, 1939				
00			256			5.77	
01			255			5.45	
02			255			5.16	
03			247			4.79	
04			261			4.55	
05			271			4.49	
06			264	1.61		5.20	0.52
07			241	2.52		7.75	0.73
08		238	251	3.12	4.49	9.33	0.94
09		227	265	3.46	4.81	10.11	1.39
10		219	274	3.68	5.09	10.69	1.24
11		216	282	3.79	5.20	11.09	1.24
12		217	286	3.88	5.34	11.21	1.18
13		217	285	3.81	5.24	11.21	1.26
14		223	273	3.72	5.02	10.99	1.22
15		228	264	3.52	4.85	10.67	1.28
16		231	246	3.21	4.38	10.44	0.95
17			244	2.56		10.16	0.69
18			236	1.65		9.89	0.61
19			227	0.85		8.73	
20			236	0.77		7.62	
21			249			7.10	
22			250			6.67	
23			255			6.18	

WATHEROO MAGNETIC OBSERVATORY,
Watheroo, Western Australia, October 25, 1939

Cheltenham Magnetic Observatory

October to December, 1939—*Concluded*

November 13—A disturbance began gradually about 01^h GMT, November 13, and increased in activity about 07^h. The outstanding feature was a large baylike disturbance in H beginning at 11^h and lasting about two hours. The disturbance lasted altogether about two days. Ranges: D, 27′; H, 133 gammas; Z, 95 gammas.

December 6-9—A disturbance of moderate intensity but lasting several days began December 6 at 20^h GMT. At that time H decreased 110 gammas in one hour. Ranges: D, 47′; H, 121 gammas; Z, 95 gammas.

December 20-22—December 20, 21, and 22 were moderately disturbed days beginning with short-period perturbations of small amplitude at $12^h\ 07^m$ GMT, December 20. At $05^h\ 50^m$, December 21, the perturbations became irregular and assumed greater amplitudes. Ranges: D, 23′; H, 96 gammas; Z, 39 gammas.

Albert K. Ludy, *Observer-in-Charge*

Tucson Magnetic Observatory

October to December, 1939

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h\ 23^m.3$ W. of Gr.)

October 3-4—A storm began very indefinitely about 08^h GMT, October 3, but did not become severe until about 01^h, October 4, although in the meantime average H had decreased considerably. Between 01^h and 05^h, H executed a fairly deep bay, while the other elements were moderately disturbed. Except for a continued low H, the storm ended at about 05^h.

October 5-6—A very moderate disturbance began about 10^h GMT, October 5, and lasted about 25 hours. The only important activity occurred between 05^h and 07^h, October 6. During this interval H varied through a range of about 100 gammas, while the range of D at the same time was about 18′.

October 13-19—A severe storm began sharply at $02^h\ 03^m$ GMT, October 13, with an increase in H of about 42 gammas, followed almost immediately by larger fluctuations. At the same time D oscillated through a range of a few minutes, and Z was slightly disturbed. Short-period oscillations predominated throughout the storm, even though some of the amplitudes were quite large. The minimum of H for the storm came at $23^h\ 06^m$, October 13, its total range being 283 gammas. Thereafter the storm subsided somewhat for about three hours, and then became more violent again. At 4^h, October 15, there was a sudden burst of activity lasting about 2.5 hours. The storm proper ended about 09^h, October 15, but the elements continued moderately disturbed until about 12^h, October 19.

December 6-8—A moderate storm began about 20^h GMT, December 6, and ended about 11^h, December 7, except that a slight degree of disturbance continued until the end of December 8. The principal activity occurred between 03^h and 10^h, December 7, and consisted chiefly of moderately short-period fluctuations in H.

John Hershberger, *Observer-in-Charge*

THE IONOSPHERE AT HUANCAYO, PERU, JULY TO SEPTEMBER, 1939

By H. W. Wells

This report on ionospheric conditions is in continuation of those published in preceding issues of this Journal[1] submitting results of continuous multifrequency ionospheric recordings at the Huancayo Magnetic Observatory, Department of Terrestrial Magnetism, Carnegie Institution of Washington. The current data for the months July, August, and September, 1939, are obtained from recordings for each hour of the day and for every day of the month except for short intervals necessary for maintenance of the equipment.

Table 1 contains mean hourly values of virtual height, critical frequency, and lowest frequency received, for the third quarter of 1939. Figure 1 presents the data of Table 1 in graphical form. The following general discussion of characteristics is pertinent:

(1) *F-region*—The general upward trend of virtual heights during daylight hours which has been effective since April, 1939, continued through July and August but was followed by a downward break in September. The characteristic post-sunset hump remains clearly defined with the maximum effect at 19^h. Average maximum heights during the 24 hours were recorded at noon July and August. In September, the maximum heights of the day were observed at 19^h. The trend of evening peak-values is upward, in contrast to the downward trend active during the entire second quarter of 1939. These features are similar to the general characteristics outlined for the year, 1938, in a summary of ionospheric data from Huancayo[2] which called attention to the apparently anomalous conditions of maximum daytime heights at Huancayo around June and December, and of maximum evening heights around March and September.

In contrast to the decreasing trend of *F*-region critical frequencies which was active from February through June, the tendency during this quarter has been to somewhat greater values during July and August, with a sharp rise in September. Whereas the lowest average values for 1938 were recorded in June, 1938, the lowest values for 1939 apparently have been recorded in July, 1939. Comparison shows results for July and August, 1939, are lower than in 1938, while $f^\circ_{F_2}$ for September, 1939, is greater than in 1938.

(2) *F_1-region*—Virtual heights of the F_1-region show an upward characteristic during this entire quarter in contrast to the slight downward trend during the last quarterly period. Lowest heights of the day are generally recorded in early afternoon hours as illustrated in Figure 1.

Maximum F_1-region critical frequencies are consistently recorded around noon. The trend of maximum values during this quarter is very flat with a slight rise in September. Comparison with data for the same period of 1938 reveals no significant difference.

(3) *E-region* Since July, tabulations of *E*-region virtual heights have been discontinued because of the absence of significant variations or trends. Following the decreasing values of *E*-region critical frequencies which have been effective from January through June, the average results for this quarter show a steadily increasing characteristic. This

[1] Terr. Mag., **43**, 169-171, 257-260, and 467-470 (1938); **44**, 85-88, 195-198, 321-325, and 395-399 (1939).
[2] Terr. Mag., **44**, 326-334 (1939).

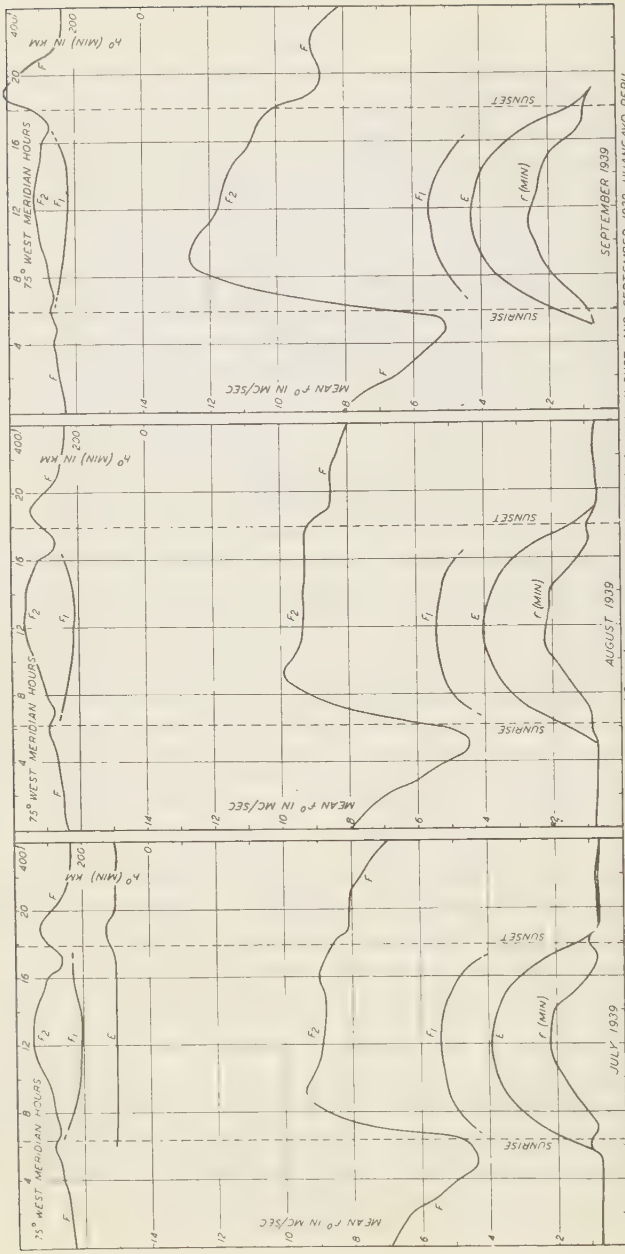


FIG 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, JULY, AUGUST, AND SEPTEMBER, 1939, HUANCAYO, PERU

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, July to September, 1939*

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
	July, 1939							*August, 1939*							*September, 1939*						
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00	100		232	0.71		6.92	0.70			237			7.97	0.74			235			8.08	
01			236	0.70		6.66	0.70			248			7.55	0.72			239			7.53	
02			242	0.70		6.33	0.70			249			6.95	0.69			252			6.59	
03			247	0.70		5.49	0.70			257			5.91	0.67			259			5.97	
04			263	0.68		4.91	0.68			265			5.11	0.67			268			5.40	
05			270	0.68		4.34	0.68			274	0.70		4.47	0.67			259	0.70		5.01	0.68
06	104		287	1.30		4.53	1.03			292	1.54		5.09	0.83			279	1.93		7.00	0.85
07	103	252	272	2.41	4.41	7.12	0.81		253	275	2.57	4.35	7.74	0.87		255	268	2.83	4.53	10.08	1.34
08	100	233	286	3.03	4.91	8.75	1.10		243	298	3.20	4.95	9.19	1.22		247	282	3.52	4.91	11.77	1.82
09	101	219	293	3.48	5.15	9.39	1.47		231	312	3.58	5.19	9.88	1.57		237	289	3.87	5.20	12.57	2.20
10	100	209	308	3.71	5.25	9.21	1.77		222	329	3.83	5.33	9.70	1.91		232	306	4.12	5.38	12.49	2.38
11	100	207	336	3.85	5.35	8.98	2.09		215	349	3.98	5.38	9.40	2.22		225	312	4.25	5.44	12.08	2.58
12	100	205	350	3.91	5.42	8.88	2.18		216	362	4.01	5.42	9.35	2.16		221	321	4.26	5.51	11.72	2.48
13	100	203	347	3.84	5.37	8.83	2.14		213	358	3.93	5.36	9.30	2.07		220	321	4.15	5.44	11.63	2.31
14	100	207	342	3.72	5.32	8.78	2.05		216	358	3.78	5.29	9.33	2.07		223	313	4.00	5.26	11.43	2.21
15	100	217	322	3.49	5.08	8.83	1.46		224	342	3.55	5.14	9.26	1.65		229	302	3.66	4.96	11.14	2.03
16	101	229	306	2.99	4.81	8.99	1.02		240	322	3.09	4.80	9.26	1.23		247	298	3.18	4.59	10.74	1.50
17	102	230	260	2.33	4.20	8.81	0.78			270	2.43		9.29	0.92			276	2.43		10.54	1.00
18	118		299	1.24		8.54	1.04			308	1.32		9.17	0.97			325	1.29		10.05	0.96
19	130		374	0.75		8.08	0.73			343	0.73		8.55	0.72			410	0.68		8.82	0.68
20	100		294	0.77		8.09	0.73			302			8.48	0.69			371			8.69	
21	100		252	0.78		8.04	0.75			259			8.51	0.72			307			8.90	
22	100		236	0.83		7.67	0.77			249			8.34	0.76			247			8.97	
23	95		232	0.76		7.39	0.73			240			8.18	0.79			235			8.63	

effect may be readily interpreted for this location (12° south) on the basis of ionization by ultraviolet radiation.

(4) *Lowest frequency received*—The lowest frequency recorded during the sweep through the frequency-range from 16.0 to 0.516 mc/sec may be used as an indication of relative absorption of the exploring signal in the lower atmosphere. A slight upward trend is observed during this quarter. Apparently, relative absorption follows a diurnal characteristic similar to *E*-region ionization. Following steady nighttime values absorption increases smoothly from about 05^h to a maximum at midday, and decreases smoothly to steady values at night by about 19^h. A diurnal characteristic of this nature is probably caused by a region below the *E*-region which is normally ionized by ultraviolet radiation but which is invisible to radio-exploration equipment of this type.

Table 2—*Root-mean-square values of F_2-region critical frequencies ($f^\circ_{F_2}$), Huancayo Magnetic Observatory, July to September, 1939*

EST	July	Aug.	Sep.	EST	July	Aug.	Sep.
h	*mc/sec*	*mc/sec*	*mc/sec*	*h*	*mc/sec*	*mc/sec*	*mc/sec*
00	6.97	8.01	8.12	12	8.91	9.41	11.77
01	6.72	7.60	7.60	13	8.86	9.36	11.67
02	6.40	7.02	6.66	14	8.80	9.39	11.46
03	5.56	5.98	6.04	15	8.85	9.32	11.16
04	5.03	5.20	5.50	16	9.02	9.30	10.76
05	4.44	4.58	5.14	17	8.82	9.32	10.57
06	4.59	5.16	7.08	18	8.55	9.23	10.09
07	7.14	7.77	10.13	19	8.11	8.58	8.87
08	8.78	9.21	11.81	20	8.13	8.52	8.74
09	9.42	9.91	12.63	21	8.11	8.55	8.97
10	9.24	9.74	12.55	22	7.71	8.39	9.04
11	9.01	9.46	12.14	23	7.41	8.22	8.68

Table 2 gives root-mean-square values of *F*-region critical frequencies for the same period. Since ionization is proportional to the square of frequency, these data are more representative of *average ionization* than the normally used means of critical frequencies. The differences between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 are an approximate measure of the scatter in individual observations during the month for that particular hour. Root-mean-square values for *E*-region, F_1-region, and minimum frequency received, have now been discontinued because of the absence of appreciable differences between the root-mean-square and arithmetical-mean values.

Huancayo Magnetic Observatory,
Huancayo, Peru, December 7, 1939

THE LOCAL VARIATION OF ATMOSPHERIC POTENTIAL-GRADIENT MEASURED AT TAIHOKU, FORMOSA, JAPAN

By K. Ogasahara

In spite of the importance of the study of atmospheric electricity in tropical regions, there are practically few data of observations and many problems remaining still unsolved.

Formosa is an island extending over the north temperate and the tropical zones, and under both continental and marine meteorological influences it shows a special feature in weather-type, for example, the Island is very often made the battle-field of a polar continental air-mass (Siberian) and a tropical marine air-mass (Pacific Ocean) coming into collision to give rise to a great disturbance in the atmospheric-electric field there.

The author is interested in the phenomena in atmospheric-electric fields—in the phenomena proper of course, but what attracts him most is that part of the phenomena which he regards as connected with the dynamical study of weather. He has been employing himself, therefore, in investigating, through the observation of variation of atmospheric-electric fields, the characters of air-masses as well as variation in construction of the atmosphere on the occasion of two air-masses coming opposite, or coming into collision—that is, variation of weather.

The author purposes in the present treatise to report the results of his studies on the normal electrical condition at Taihoku in its relations to meteorological elements based upon the observational data obtained during June 1934 to July 1936. These in comparison with the analogous ones obtained by Deppermann [see 1 of "References" at end of paper] at Manila, which is a place approaching Formosa in geographical position, may excite interest. Especially smaller values of potential-gradient at Taihoku, among generally smaller values all over the Pacific regions than in the European regions, are to be noted. The final discussions of the experimental data take into account my conclusions as to "the effect of temperature and water-vapor on diffusion-coefficient of ions in air:" (1) Why is potential-gradient generally low at Taihoku, which is situated in a tropical humid region? (2) Why does the morning maximum of potential-gradient occur all over the world exclusively in summer when solar radiation is vigorous? (3) Why does the negative potential-gradient occur during silent thunder-storms?

Site and apparatus

The observations were made at the Meteorological Station (25° 01′ north, 121° 31′ 44″ east, elevation 10.4 meters above sea-level) of the Institute of Meteorology and Geophysics of the Taihoku Imperial University. The location is free from the dust of streets, for it is about four km from the center of Taihoku, and is on an experimental farm of about ten hectares.

A wire was stretched between the tip of a pole and a wall of the room housing an electrometer connected through the wall. Each end of the

wire was insulated by an amber insulator. To keep the insulator-surfaces dry, flasks of raw natrium were suspended close to each one. On each insulator-shell, at the end left open, an electric radiator was installed for drying dew and rain. An ionium-collector was hung from the wire and was kept at a height of two meters. The wire was connected in the room to a pendulum-type self-recording electrometer, which was originally constructed by our Institute [2] to record a range of $\pm 4\times10^3$ volts (Fig. 1). Various devices for insulation were applied to the apparatus.

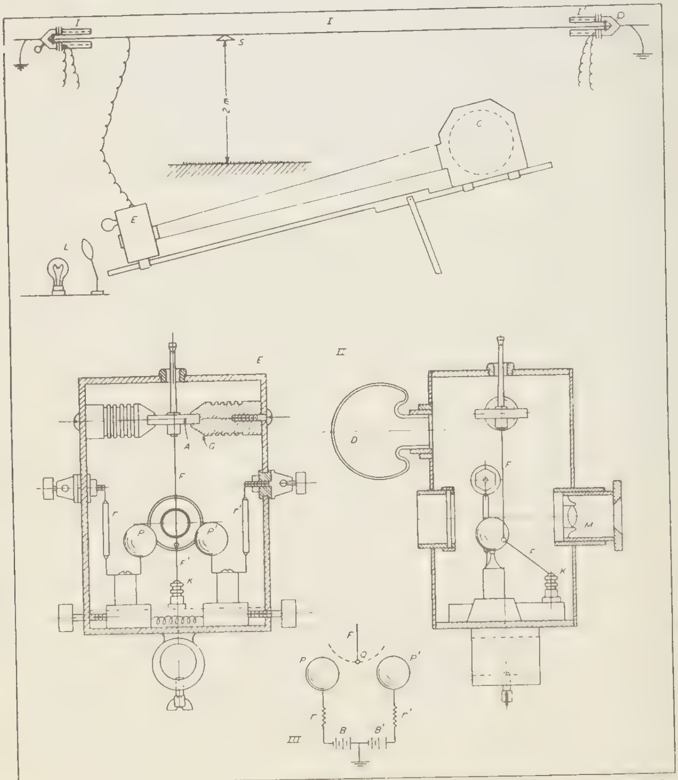


FIG. 1—DIAGRAM OF POTENTIAL-RECORDER INCLUDING INSULATION-DEVICE(I), AND OF CONSTRUCTION OF PENDULUM-TYPE ELECTROMETER OF SHIRATORI AND TATARA'S DESIGN(II,III)

To determine the reduction-factor for the true value of potential-gradient, another wire and collector were used with a Wulf bifilar electrometer placed in an open field about one-half kilometer from the Institute for simultaneous comparison with the main electrometer. Thus a reduction-factor (1.4)—though the author does not maintain it is absolutely correct—was obtained; and all the recorded potentials have been divided by 1.4 instead of the actual height of 2.0 meters to reduce them into

potential-gradient in volts per meter. The electric resistance of the recording apparatus (the ionium-collector plus the electrometer) was within the range of $10^{18} \sim 10^{12}$ ohms. Values that were recorded during bad insulation were carefully rejected for the statistical survey; they were easily detected by the absence of fine oscillations in the photographic curve. Tests of insulation were made once a fortnight.

The difficulty of maintaining absolute insulation in the tropical climate of Taihoku is considerable and three years were taken to overcome it. Eventually we succeeded in constructing an apparatus, the insulation of which remains good under the conditions of our warm and humid tropical climate. Spiders are numerous here and their cobwebs, as at Manila [1] and elsewhere, gave much trouble. To eliminate this difficulty a delicate windmill, which was rotated by the lightest wind, was arranged so as to break promptly any cobweb spun between the ionium-collector and its supporting rod and the wall of the building housing the electrometer. Another source of trouble is dew, which possibly causes the low values recorded before dawn. As to the influence of dew upon the activity of ionium-collector the author concluded from experiments that wetting of the surface of the ionium-collector by dew is not a factor in the low potential-gradient recorded at Taihoku.

TABLE 1—*Monthly average mean hourly atmospheric potential-gradient in volts per meter at Taihoku, 1934-1936*

Time 120° EMT	Month and number of days											
	Jan. (24)	Feb. (21)	Mar. (25)	Apr. (26)	May (19)	June (22)	July (25)	Aug. (13)	Sep. (19)	Oct. (24)	Nov. (19)	Dec. (27)
h h												
0– 1	29.6	18.1	17.3	6.6	8.0	16.0	9.7	0.6	8.4	19.3	11.0	40.0
1– 2	33.3	19.2	16.4	6.2	7.0	16.0	8.7	0.0	7.2	15.6	14.5	41.0
2– 3	26.4	22.8	16.4	5.9	5.0	15.7	8.4	0.0	6.8	16.4	14.5	38.0
3– 4	32.9	26.8	17.4	5.3	4.0	17.0	7.0	0.0	6.5	14.0	18.0	37.2
4– 5	35.4	21.2	15.0	5.2	7.0	16.7	6.4	0.0	11.6	18.8	28.6	38.2
5– 6	39.3	28.3	16.9	5.7	10.0	17.7	5.5	2.4	14.2	25.8	31.4	43.0
6– 7	35.7	32.2	15.0	6.4	8.0	34.1	32.8	35.9	25.6	29.6	32.9	50.7
7– 8	33.3	41.9	16.8	10.8	10.0	73.7	83.6	60.6	54.0	25.2	45.5	50.7
8– 9	33.3	43.3	26.6	12.9	10.0	100.0	132.8	79.4	45.0	33.8	49.5	53.5
9–10	37.9	37.1	28.2	14.5	15.0	87.5	93.8	44.1	45.4	26.4	45.2	57.9
10–11	37.5	29.2	32.5	20.7	15.6	62.1	68.1	57.5	45.5	32.1	47.1	57.5
11–12	41.0	29.6	34.8	19.7	10.0	60.0	67.8	38.0	33.9	31.7	40.5	63.2
12–13	48.2	34.8	37.7	40.7	7.0	48.3	54.2	22.0	30.4	41.1	42.0	54.1
13–14	36.6	36.2	36.8	30.0	12.0	42.4	44.5	18.0	24.0	36.9	28.0	55.0
14–15	37.0	34.2	29.0	24.8	11.1	32.8	32.1	11.4	28.0	32.9	27.5	50.3
15–16	31.0	31.6	23.8	19.6	8.9	32.4	35.4	11.5	20.5	30.4	28.4	45.4
16–17	38.2	23.5	31.5	20.3	5.6	39.1	26.1	10.0	26.2	34.1	29.5	47.9
17–18	44.6	25.2	36.4	10.0	10.0	40.0	18.3	17.9	26.3	33.6	25.8	49.6
18–19	41.1	23.9	28.8	5.9	10.0	37.2	18.1	17.9	19.6	24.3	23.7	38.9
19–20	37.0	19.2	24.1	6.8	8.9	20.3	17.6	18.0	19.2	20.0	24.0	32.8
20–21	24.6	24.4	20.0	4.7	7.8	18.7	15.5	8.7	19.6	21.7	30.0	36.5
21–22	26.5	25.4	18.9	7.6	8.9	19.9	15.8	6.2	14.6	20.4	26.0	33.2
22–23	24.2	20.4	18.6	3.8	12.2	17.9	11.3	8.8	10.0	19.6	21.4	40.7
23–24	23.7	19.6	19.3	4.3	8.9	16.8	10.5	5.3	6.8	19.6	18.0	38.5
Means	34.5	27.8	24.1	12.4	*9.2*	*36.8*	34.3	*19.8*	22.9	26.0	29.1	*45.6*

Results of observation

In the statistical treatment of the data all the "abnormal variations" accompanied by heavy rain or thunder-storms were rejected, as a discussion of these during the same period has already been published by Professor Shiratori [2] of our Institute. Positive variations caused by fog and haze as well as those which appear in early morning were counted.

Table 1 gives a summary of the results showing monthly average mean hourly atmospheric potential-gradient in volts per meter; at the top of the columns are given the month and the number of days on which values were obtained during June, 1934, to July, 1936, while the last line contains the monthly means. Table 2 contains the annual and seasonal average mean hourly atmospheric potential-gradient; Table 3 summarizes the frequency of thunder-storms as determined from the photographic records.

TABLE 2—*Annual and seasonal average mean hourly atmospheric potential-gradient in volts per meter at Taihoku, 1934-1936*

Time 120° EMT	Annual mean	Season			
		April	Summer (Jun. to Aug.)	Sep.	Winter (Oct. to Mar.)
h h					
0– 1	16.3	6.6	10.0	8.4	23.4
1– 2	16.6	6.2	9.5	7.2	24.0
2– 3	*15.7*	5.9	9.3	6.8	*22.9*
3– 4	16.5	5.3	9.2	*6.5*	24.8
4– 5	17.8	*5.2*	*8.8*	11.6	26.4
5– 6	20.9	5.7	9.2	14.2	30.9
6– 7	28.2	6.4	33.9	25.6	32.9
7– 8	41.3	10.8	74.8	*54.0*	35.3
8– 9	*51.7*	12.9	*109.2*	45.0	40.0
9–10	44.8	14.5	80.7	45.4	38.9
10–11	41.8	20.7	63.6	45.5	39.6
11–12	38.3	19.7	58.5	33.9	40.8
12–13	40.0	*40.7*	45.1	30.4	*43.8*
13–14	34.9	30.0	38.0	24.0	39.0
14–15	30.6	24.8	27.9	28.0	35.7
15–16	27.7	19.6	29.1	20.5	32.1
16–17	29.0	20.3	27.4	26.2	34.8
17–18	29.0	10.0	26.2	26.3	36.8
18–19	22.0	5.9	25.1	19.6	25.6
19–20	21.0	6.8	18.7	19.2	26.6
20–21	19.8	4.7	15.2	19.6	26.3
21–22	19.2	7.6	15.2	14.6	25.2
22–23	18.0	3.8	13.2	10.0	24.6
23–24	16.8	4.3	11.7	6.8	23.7
Means	27.6	12.4	32.1	22.9	31.6

Diurnal variations

At Taihoku the diurnal variation in potential-gradient differs conspicuously from that of the temperate zones. As a rule, a double oscillation is recognized in the temperate zones where two maxima occur at 7^h to 10^h and 19^h to 21^h and two minima at 4^h to 6^h and 12^h to 16^h

TABLE 3—*Monthly average mean hourly-frequency percentage of thunder-storms at Taihoku, 1934-1936*

Time 120° EMT	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
h h												
0– 1	13	..	16	3	..	..	5	..	4	4	..	10
1– 2	10	4	10	3	..	..	4	..	4	4	..	3
2– 3	17	4	10	3	..	..	3	..	4	11	..	..
3– 4	20	4	13	..	..	..	5	..	..	4	..	3
4– 5	7	4	10	3	..	..	8	..	4	4	..	3
5– 6	7	8	6	7	..	..	3	..	4	8	..	..
6– 7	7	8	16	7	..	3	3	..	8	4	..	3
7– 8	10	16	10	8	..	3	3	..	4	4	..	3
8– 9	10	4	6	10	..	..	3	..	8	8	..	7
9–10	7	4	10	10	..	..	6	..	8	4	..	7
10–11	7	4	10	7	10	..	9	..	8	8	..	7
11–12	7	..	6	..	..	3	9	..	8	4	..	7
12–13	3	4	3	7	..	3	13	..	4	5	..	7
13–14	..	7	10	7	..	16	19	..	17	7	..	10
14–15	7	7	6	3	..	20	36	12	17	14	..	7
15–16	3	11	6	7	..	32	50	19	20	11	5	7
16–17	3	15	16	10	..	25	25	20	16	10	5	7
17–18	3	15	19	10	..	19	30	13	21	11	5	20
18–19	3	8	19	10	..	14	6	..	12	3	10	3
19–20	7	11	13	7	..	10	8	6	4	..	5	3
20–21	5	7	19	..	..	6	5	6	4	3	..	3
21–22	13	11	13	3	..	..	5	..	8	3	9	7
22–23	13	7	10	3	..	..	5	..	8	7	..	7
23–24	10	7	10	7	..	3	5	..	8	9	..	7
Means	8	7	11	6	0	4	7	3	8	6	2	6

in summer, though in winter only the afternoon-maximum and midnight-minimum are apparent. At Taihoku, on the other hand, as shown in Figure 2, there are only traces of the maximum and minimum in the afternoon, while the maximum in the morning and the minimum at midnight are very conspicuous. Thus the day starts with a very low potential-gradient which is equivalent to the midnight-minimum (15.7 volts per meter) at 2^h to 3^h, then increases rapidly with sunrise and reaches a well-marked morning-maximum (51.7 volts per meter) at 8^h to 9^h, and thereafter decreases slowly to the minimum at midnight. This is similar to the diurnal variation at Manila as reported by Deppermann.

The gradient-curve shows a comparatively large amplitude (36.0 volts per meter) compared with the mean value (27. 6 volts per meter) and assumes a regular form, though not a simple sine-wave. It seems to be affected directly by the local effect of solar radiation and thunder-storms as is discussed later. From the results of the monthly diurnal distribution of potential-gradient, which is graphically represented in Fig. 2, the diurnal variations at Taihoku may be grouped under the following distinct types: (*a*) Summer (June to August); (*b*) winter (October to March); and (*c*) intermediate (April and September).

It is to be noted that these seasonal types, apparent in the gradient-

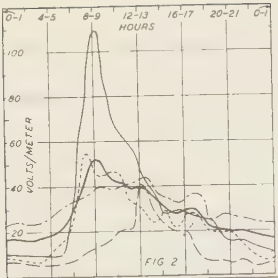
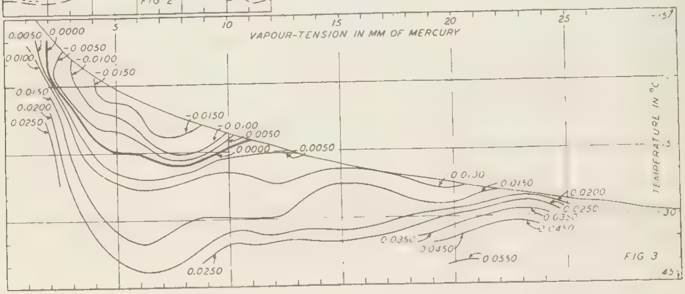


FIG. 2—ANNUAL AND SEASONAL AVERAGE MEAN HOURLY ATMOSPHERIC POTENTIAL-GRADIENT IN VOLTS PER METER AT TAIHOKU, 1934-36

LEGEND
ANNUAL MEAN
SUMMER (JUNE TO AUGUST)
WINTER (OCTOBER TO MARCH)
APRIL
SEPTEMBER

FIG. 3—DIFFERENCE BETWEEN NEGATIVE-DIFFUSION COEFFICIENT AND POSITIVE-DIFFUSION COEFFICIENT



curves, correspond strictly with the seasonal types of climatic elements at this place, as described below:

(*a*) *Summer type*—From June to August the amplitude of the diurnal variation of the potential-gradient is quite large. A well-marked maximum (109.2 volts per meter) occurs at about 8^h to 9^h and a minimum (5. 2 volts per meter) occurs before sunrise at 4^h to 5^h, whereas there is hardly any trace of an extreme in the afternoon, the value decreasing slowly until it reaches the minimum early in the morning. The amplitude is about 100 volts, nearly three times the mean potential-gradient (Table 2 and Fig. 2). In May, the abnormal positive rise of potential-gradient in the morning does not occur; in June it suddenly becomes conspicuous; in July it reaches its maximum; and during August and September it begins to decrease, disappearing in October (Tables 1 and 6). It is quite certain that such an abnormal positive increase is accompanied by the strong convection characteristic of this season which is caused by the intense insolation in calm weather. In fact, such an abnormal increase appears only under such meteorological conditions, and of course disappears in cloudy, rainy, and windy weather (Table 6). It appears that in the afternoon, the direct action of thunder-storms -often brought about by the warm and humid southwest monsoon—has some effect on the variation of potential-gradient. Of course, our investigation is concerned only with the normal variation of the potential-gradient, and many days on which there was a storm in the neighborhood of the Station have been ruled out of the statistical survey. However, the thunder-storm in this season, as shown in Table 3, occurs most frequently from 13^h to 18^h, and as indicated by Professor Shiratori and Mr. Tatara [2] the so-called "heat-storm" shows a preponderantly

negative variation almost without exception. This type of thunder-storm will be called "dumb-thunder-storm" or "dry-heat-storm" instead of "heat-storm" since it is attended by no rain or by very little rain. It is probable that even when the meteorological condition does not develop a thunder-storm, it depresses the potential-gradient near the Earth's surface in the summer afternoon and the same is also probably applicable to the annual mean diurnal variation. From June to September, a typhoon now and then passes by Formosa and this, as well as the thunder-storm produced by the southwest monsoon, often brings heavy rain disturbing the normal electric field and large-scale field-oscillations of short period are recorded.

(*b*) *Winter type*—From September to April the amplitude of the diurnal variation of the potential-gradient becomes conspicuously less than in summer. But the most notable characteristic of this season is the fact that the maximum, which would be expected to occur in the morning, occurs towards noon, and the minimum is reached about midnight (from 2^h to 3^h). The maximum value of the potential-gradient is 43.8 volts per meter and the minimum is 22.9 volts per meter; thus the oscillation of potential-gradient amounts to no more than 20 volts or about 65 per cent of the mean (Table 2 and Figure 2). The winter monsoon begins to blow in the middle of September, becoming stronger and stronger until November, after which it grows weaker and weaker until it disappears in May. During the winter monsoon the wind blows usually from the northeast bringing drizzly weather which greatly diminishes solar radiation. In order to examine the effect of such local and seasonal climatic effects on potential-gradient, a statistical study was made of wind-velocity and precipitation (Table 5). In this study, a day is defined as calm when the diurnal mean wind-velocity is less than 0.1 meter per second, as drizzly when the diurnal precipitation is less than three mm (though greater than zero). The first class, showing calm and dry, has the largest mean potential-gradient (43.1 volts per meter); the second class, showing calm and drizzly days, has the middle mean potential-gradient (40.9 volts per meter); the third class, which represents the total mean of potential-gradient, shows the minimum (32.6 volts per meter). A comparison of these three classes indicates that the winter monsoon (seasonal mean, 3.5 meters per second) and rains (seasonal mean, 4.0 mm per day) cause a depression of the potential-

TABLE 4—*The annual variation of meteorological elements at Taihoku (latitude 25° 01′ north, longitude 121° 31′ 44″ east, elevation above sea-level 10.4 meters)*

Element	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
mp. °C												
Mean	15.2	14.8	16.9	20.7	24.1	26.6	27.8	27.8	25.9	22.7	19.9	17.1
Maximum	17.1	18.0	20.9	24.7	28.4	31.1	32.4	32.7	30.0	26.1	23.5	20.2
Minimum	11.8	12.4	13.2	17.3	21.2	28.0	24.3	24.1	23.0	20.0	16.9	14.4
lative humidity, per cent	84	85	84	83	84	80	82	81	81	82	84	86
por tension at 10^h	10.7	11.8	11.7	15.3	19.5	21.7	22.4	22.1	20.7	17.4	15.0	13.1

TABLE 5—*Atmospheric potential-gradient during the winter monsoon (October to March) at Taihoku, 1934-1936*

Time 120° EMT	Class A*	Class B*	Total Mean	Time 120° EMT	Class A*	Class B*	Total Mean
0– 1	39.3	16.7	23.9	12–13	56.0	48.0	43.5
1– 2	44.7	21.0	25.7	13–14	54.0	47.0	38.9
2– 3	34.0	19.1	24.4	14–15	54.0	46.0	35.9
3– 4	20.0	19.1	26.5	15–16	48.0	52.0	32.2
4– 5	49.3	23.6	27.9	16–17	52.0	61.0	35.0
5– 6	48.7	34.5	32.1	17–18	54.0	72.0	37.6
6– 7	35.3	44.0	33.8	18–19	38.6	46.7	32.2
7– 8	44.0	41.0	36.3	19–20	33.6	37.5	27.9
8– 9	52.7	48.0	40.7	20–21	26.4	31.1	27.2
9–10	55.3	38.2	41.1	21–22	29.2	22.9	26.1
10–11	57.3	35.4	40.7	22–23	26.1	18.5	25.4
11–12	59.3	34.0	42.2	23–24	22.0	24.3	24.3
Means of 24 hourly values					43.1	40.9	32.6

*Class *A* includes potential-gradient during calm days with no rain; class *B* includes potential-gradient during calm days with drizzly weather.

gradient during that period. But there appears a characteristic difference between the first and the second class: During the quiet night (20^h to 6^h) the potential-gradient of the first class is higher than that of the second class but the latter has a higher value than the former in late afternoon when a maximum potential is reached. The first class does not always mean calm and sunny weather, but the maximum in the morning—conspicuous essentially in midsummer—occurs also even in midwinter when the weather is calm and sunny (Table 6). The author has reached the conclusion that throughout the winter the effect of the cloudy, drizzly, and windy weather is to depress the potential-gradient. Moreover, at this season, as is shown in Table 3, thunder-storms accompanied by heavy rain, resulting from an invasion of "cold front," frequently occur. This "cold front" frequently disturbs the atmospheric-electric field, producing large-scale field-oscillations of short period, though its invasion is not regular like that of the summer squall.

(*c*) *Intermediate type*—In Formosa, spring and autumn are not so distinct as the seasons of winter and summer monsoon, and this climatic

TABLE 6—*Annual distribution of frequency of abnormal rise of potential-gradient on clear sunny mornings and estimated mean potential-gradient*

Value	Jan.	Feb.	Mar.	Apr.	May*	June	July	Aug.	Sep.	Oct.	Nov.	D
Frequency in per cent	16	7	3	3	....	78	86	95	68	32	19	3
Mean potential-gradient in volts/meter	36.2	40.8	23.9	12.7	...	128.0	95.6	61.4	48.1	28.5	46.7	5

*Frequency is equal to zero.

peculiarity reveals itself as a characteristic diurnal variation of potential-gradient at the change of monsoon. Thus in April, though the potential-gradient is only half the value found in March, it has a diurnal variation of the winter type, while in May the diurnal variation has an intermediate type between those of summer and winter and is so depressed that it has practically no maximum in the morning nor at noon. The maximum value (15.6 volts per meter) occurs from 10^h to 11^h, and the minimum (4.0 volts per meter) that occurs from 3^h to 4^h is scarcely recognizable. The amplitude of diurnal variation is very slight (11.6 volts) and moreover, the Earth's electric field is very quiet (Table 3). May is the season when Taihoku is entirely occupied by the tropical marine air-mass and the wind-velocity is the least of the year. The weather is warm and humid and the sky is covered with haze. The transition of season is more rapid from summer to winter than from spring to summer. In the former case transition from one seasonal type to the other is also very rapid. A comparison of the diurnal variation of potential-gradient in September and November shows that in the latter not only the mean potential-gradient increases but the maximum in the morning disappears altogether showing a winter type. Thus the normal potential-gradient seems to depend for the most part on the climatic elements.

Annual variation

The variation of the monthly mean of the potential-gradient is given in Table 1. It will be noticed that there are two maxima and two minima instead of a single maximum and a single minimum usually found at most other stations. One maximum occurs in June (36.8 volts per meter), the other in December (45.6 volts per meter); one minimum occurs in May (9.2 volts per meter), the other in August (19.8 volts per meter).

Here in Taihoku also, monsoon plays an important part in the determination of the character of the variations in atmospheric potential-gradient. From May to August, on calm nights, abnormally low values of the potential-gradient are usually recorded, especially in May if the weather is calm. In May, Taihoku is already invaded by a tropical marine air-mass brought by the southwest monsoon, the wind-velocity is very low and the potential-gradient shows the lowest value of the year. It is especially remarkable that in May the maximum in the morning practically disappears. For these reasons May has been excluded from the type-classification and has been treated independently.

In August, 1934, no typhoon visited the vicinity of Formosa and there was a season of clear weather—almost every day was clear, a rare occurrence in Taihoku at that season—with a steady southeast wind of moderate intensity both day and night. There was an anticyclone over Taihoku with its central region in the Pacific Ocean. The exceptional development of this anticyclone suppressing the southwest monsoon and bringing into prominence the southeast wind finally gave rise, as a result of the topography of the region, to a "Föhn," accompanied by a very low monthly mean potential-gradient. In August the potential-gradient, owing to the Föhn-influenced weather, tends towards lower values than in June or July and we have an annual minimum

comparable to that of May. This southeast wind often brings, also from October to December, Föhn-influenced dry and clear weather with depressed values of potential-gradient. During the activity of the Föhn, convection is diminished and naturally enough the maximum in the morning is greatly depressed.

The winter monsoon, that is, northeast wind, on the contrary, causes high values of potential-gradient in general. But the high value of the annual maximum in December is not to be attributed solely to the monsoon. There are other factors two of which may be mentioned. In December (1) the weather is generally fine, frequently causing the maximum in the morning and (2), contrary to the summer type, the depression in the afternoon does not occur and sometimes maxima are even recorded.

It will be interesting to compare the potential-gradient at Taihoku with that at other places. Fortunately we may refer in this connection to a paper by J. G. Brown [4]. For purposes of comparison values from the Pacific regions have been selected and listed in Table 7.

TABLE 7—*Annual means of potential-gradient in the Pacific regions*

Station	Latitude	Longitude	Annual mean
	°	°	*volts/meter*
Stanford	37N	122W	86
Tokyo	36N	139E	51
Taihoku	25N	122E	28
Manila	14N	121E	79*
Apia in Samoa	14S	172W	116
Christchurch	43S	172E	74

*Deppermann's "all-normal," arithmetic mean obtained from his observational results during October, 1927, to December, 1930, reported by him has been taken, in spite of his warning that "because of the uncertainty in this reduction-factor (=1.3), it is considered only tentative and the values hereafter given are expressed in volts as recorded" (the collectors stand 1.9 meters above the ground) and the value obtained by multiplying by 1.3 was used.

The annual means of potential-gradient in the Pacific regions are, in general, as may easily be seen from Table 7, remarkably smaller than those in Europe—so much so that the former does not amount to even one half of the latter—which is of the order of 150 volts per meter. The potential-gradient at Taihoku again shows a lower value than that of any other place mentioned in Table 7.

Discussion

(1) It was mentioned by Watson [3] in his report that the variation of potential-gradient could be accounted for by supposing that ". . . the Earth has a charge sufficient to cause a potential-gradient of 100 to 150 volts per meter and that local atmospheric charges which increase in the absence of wind or other mixing agents cause the remainder of the potential-gradient." Brown [4] adopted in his treatise a mean gradient of 129 volts per meter. Taking into account the fact that the values of the potential-gradient in western Europe and in the middle-latitude regions of the Continent are generally found to be far higher than this

mean value, it is not surprising that there should be some other regions on the Earth where the potential-gradient is far lower than this mean value, and that the Pacific regions to which the author refers in Table 7 should be one of these. What then is the reason or reasons for the universal depression of the absolute value of potential-gradient in the Pacific regions? In order to solve this problem, we must take up the condenser-field of the Earth and examine the feature of Mauchly's "variation on universal time," or, more properly, "unitary variation" and find the reason why its mean value and its amplitude vary with geographical locality. This, however, is a very difficult task which the author fears is beyond the reach of the method mentioned in Brown's treatise. For, according to Brown's method, a unitary variation is first obtained from those values over a certain arbitrary ocean on which the local and meteorological disturbances do not act, and then the unitary variation over some land situated in its vicinity is computed by multiplying it by the factor $(R_0\lambda_{+0}\ R_1\lambda_{+1})$. Thus the "local variation" derived from the difference between the 24-hour component of Brown and the actual variation holds only for showing the difference of the value over a certain particular land from that over some adjoining sea. Brown's paper is very valuable but it does not contribute to the solution of the problem why the potential-gradient in the Pacific regions should show far lower absolute values than in the western European regions. Kähler [15] of Potsdam has stated that "the potential-gradient is in inverse proportion to temperature and vapor-pressure." This agrees entirely with the author's results at Taihoku.

(2) There is a report that because of the approximate inverse relation between the gradient and the conductivity near the surface, both for diurnal and seasonal changes, it is agreed that conductivity is the chief factor in determining the gradient [5]. An explanation of the variation in conductivity, therefore, becomes the essential part of the problem. Now conductivity of the atmosphere depends primarily upon the rate at which molecular ions are formed and the number of suspensoids upon which the small ions are adsorbed to form large or intermediate ions. While it must be admitted that changes in rate of formation of small ions do take place in the lower atmosphere on account of varying amounts of radon present, it is believed that this has less effect on variation in conductivity than the number of condensation-nuclei present. In fact it is quite likely that at some stations the latter may be the controlling factor [4, 7, 8, 9, 10]. But again, the rate of formation of ions at Mount Stromlo [6] varies almost inversely to the local component of the potential-gradient and the variation is of the same order of magnitude. But this is a subject for future studies. So far as the present data are available, we may say that the mean electric conductivity in the tropical zone is much higher than that in the temperate zones. The electrical conductivity at Taihoku observed by Professor Shiratori [13] has fairly large values.

No nuclei-measurements have been made at Taihoku, but the station is situated so far from the town that as nuclei in the atmosphere the dust adds nothing to the hygroscopic particles. For this reason, as far as Taihoku is concerned, neither the air-pollution caused by fires nor the dust brought by the wind to which Whipple [8], Wait [9], or

Halliday [10] refer is applicable as the explanation of the local variations of potential-gradient. The dust-nuclei to which those writers refer are rather to be replaced in this case by hygroscopic particles. For at Taihoku the weather is very humid even in winter and the so-called "dry season" is literally non-existent. It seems probable, in view of the works of Wright [11] and P. J. Nolan [12], that it is the suspension of hygroscopic particles in the air serving as so many nuclei of condensation that is most effective in the adsorption of small ions. The collection of water upon these particles and its subsequent evaporation seems to cause variation in ionic mobility, in other words, to cause great variation in the ion-spectrum and to affect electric conductivity in humid air, the small ion being easily caught by hygroscopic particles. Regarding this discussion, the author offers some observational data taken from his treatise published three years ago entitled "The effect of temperature and water-vapor on diffusion-coefficient of ions." In this paper it was reported that the diffusion of ions, especially negative small ions, is considerably affected by temperature and humidity a conclusion drawn from his precise measurements of the diffusion of small ions in the temperature-range from $-15°$ to $45°$ C and vapor-pressure up to 25 mm of mercury. Figure 3, showing the relation of the difference of the diffusion-coefficient between positive and negative small ions with temperature and vapor-pressure, is taken from this paper. As the range of the mean temperature at Taihoku is $8°$ to $34°$ C and that of vapor-pressure 8 to 25 mm of mercury (Table 4), one might easily get the impression from Figure 3 that physical conditions at Taihoku are always such that the diffusion-coefficient of the negative ion is larger than that of the positive ion. This may be said of all other places in warm and humid tropical regions. It is worthy of note in the light of Figure 3 that when the temperature is $30°$, or thereabouts, and vapor-pressure 20 to 25 mm of mercury, the coefficient of diffusion of negative ions undergoes an exceedingly wide and delicate variation with the slightest variation of temperature. In polluted or humid air ions are easily adsorbed by dust or hygroscopic particles and become inactive ionic groups with the result that the conductivity of the atmosphere is reduced. *Accordingly the potential-gradient at Taihoku should have a much larger value.* It is thus apparent that there is an incontestable incongruity between the two above-mentioned descriptions of the relation between atmospheric potential-gradient and atmospheric-electric conductivity and that between atmospheric-electric conductivity and atmospheric pollution. This suggests that the problem is more complicated than it appears. First of all, it must be noticed that in the determination of potential-gradient, variation in conductivity at all heights must be taken into consideration because the electric conductivity may vary according to the height at which it is measured. G. R. Wait [9] has published his observations of the correlations between the number of condensation-nuclei and the potential-gradient, and has brought out the fact that the variation of potential-gradient is partly due to the variation of the concentration of a cloud of condensation-nuclei situated near the surface of the Earth and partly to the height to which the cloud extends. The author is of the opinion this statement, as well as Brown's study on the

distribution of space-charge, is an important step toward the solution of this problem.

(3) In this connection a material problem is presented. In Section (2) we see that an inverse relation, though approximate, exists between the potential-gradient and the conductivity near the surface. This hypothesis is based upon the assumption that in the formula $i = F\lambda$, representing the correlation among the three factors, potential-gradient, electric conductivity, and air-earth current, the last is constant. This, however, serves to explain to a certain extent the variation but not the absolute value of potential-gradient.

The chief differences between the earth-condenser and the ordinary air-condenser are in the nature of the outer plate—one is gaseous while the other is solid—and in the conductivity one shows a variation with height while the other shows no variation. And even if we exclude these differences from consideration and assume the earth-condenser to be an ideal air-condenser in which the potential difference between the two plates is constant, the air-earth current in that case is not to be regarded as the same as the motion of charged particles in the ideal statical field. As the leading causes of this deviation from the ordinary air-condenser, we may enumerate diffusion, transpiration, turbulence, convection, and subsidence.

The influence of diffusion, transpiration, turbulence, convection, and subsidence upon electrode- and polarization-effects—As the agent of the mechanical force that acts on the electrode- and polarization-effect, we enumerate convection and subsidence, the convection the latter and the subsidence the former. Whether convection or subsidence is predominant becomes the chief concern. If we consider that the mobility of small ions at most is of the order of two to three cm/sec/volt/cm ($F = 100$ volts/meter)—far below the velocity of upward convection—we may readily ascribe the early-morning rise of potential-gradient to upward convection hindering the electrode-effect. And in the same way when the subsidence prevails, a reverse phenomenon takes place. The two following ways of explaining the nocturnal low potential-gradient in midsummer at Taihoku are proposed: (*a*) Convection and subsidence both having ceased, a period of stagnation ensues with more ions near the Earth's surface than in the daytime; the positive ion, with its larger mobility, moves easily towards the negatively charged Earth, while the negative ion shows a tendency to suspension with hygroscopic particles there. Consequently, the lowest layer near the Earth's surface becomes negative, which virtually is the same as though the Earth's surface were elevated to that extent and it may naturally be expected that the values of the potential-gradient near the Earth's surface would remain very low. (*b*) Reference is here made to Brown's curve [4] showing the diurnal variation of the space-charge at Stanford. If the same is the case at Taihoku, it follows that subsidence causes variation in the distribution of space-charge, with the result that the center of space-charge gets lower. And if in this case the ionium-collector is hung at a height of two meters from the surface, the value of potential-gradient designated is not only low, but sometimes even negative potential-gradient is recorded—as may be easily gathered from the

field-theory. The reason the author abandoned the old method of following the conductivity-potential-gradient relation in favor of his new theory for the explanation of the nocturnal variation of potential-gradient, is that the nocturnal low potential-gradient at Taihoku—sometimes zero or even negative—occurs during foggy night hours when high values are expected according to the old theory provided that the hygroscopic particle plays the same part as the dust-particle in depressing conductivity. This was proved experimentally by O. Narazaki in Tokyo; the account of his observations is to be given in a succeeding paper.

Figure 4 shows the variation-curve of potential-gradient reproduced

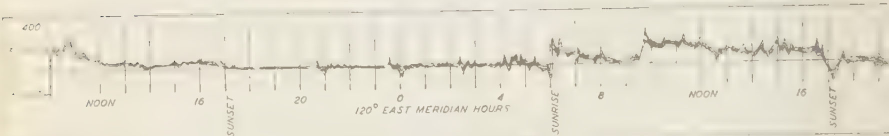


FIG. 4 —DIURNAL VARIATION OF POTENTIAL-GRADIENT AT TAIHOKU, 10h FEBRUARY 10 TO 20h FEBRUARY 11, 1939

from the original photograph) during an advection fog which enshrouded Taihoku early in the morning while the author was writing this paper (February 11, 1939). It was a phenomenally dense fog due to a depression northwest of Formosa in the East China Sea vigorously absorbing the southwest air, which continued from midnight until early morning. This fog began to form about sunset on February 10, becoming denser and denser until sunrise at 6^h February 11, when it began to dissipate until it had entirely disappeared at about 8^h. In the low values of Figure 4 the nocturnal variation of potential-gradient is shown. At sunrise it makes an abrupt increase, describing a steep ascending slope, which is thought to be due to the elevation of the center of gravity of the space-charge. No convincing explanation of these phenomena can be found in the correlation between potential-gradient and conductivity, without further reference to the diffusion of ions, the vertical flow of ions and nuclei, and the ensuing variation in the distribution of space-charge, but it seems that in the humid tropical regions condensation and subsidence during the middle of the night and evaporation and upward convection during the earlier morning hours are the chief factors in determining the variation of potential-gradient. Judging from the above experiments on the adsorption of ions the positive small ion is carried upward by convection initiated at sunrise causing elevation of the center of the space-charge or "unipolar polarization." To this may be attributed the sudden increase of the potential-gradient. The term "unipolar polarization" introduced here is in contrast to Wilson's "dipolar polarization" and signifies the elevation of the center of space-charge within the lower atmosphere to a height of 100 meters at most. This elevation may perhaps take place in two ways: (a) When those positive ions that have predominated near the surface of the Earth during the night are sent upwards against the Earth's electric field by convection at sunrise; (b) in cases when water-vapor is condensed into water particles, that is, into dense fog, negative ions are more easily adsorbed into fog than positive ions, owing to their difference in adsorba-

bility and thus the remaining positive ions, which are comparatively free, are forced upward by convection and severed from negative ions. The abnormal rise of potential-gradient coincident with sunrise on February 11 is thus explained. At Taihoku, at least, the occurrence of a fog and the simultaneous abnormal variation of potential-gradient are always in a close relation to each other.

(4) *The low potential-gradient in the summer afternoon at Taihoku*-The "heat storm" at Taihoku is not always attended by heavy rain peculiar to the tropical squall, and frequently ends in what J. Hann calls "dumb-thunder-storm," in which thunder-clouds gather but do not give rain. Ninety-nine times out of a hundred the latter results in what Wilson calls the positive dipole, the activity of which reaches, as is clearly seen from Wilson's mechanism, a height of at least some km —the region of thunder-clouds—as verified by the variation of the atmospheric potential-gradient. Thus the depression of potential-gradient in the summer afternoon at Taihoku may be accounted for by the Wilson mechanism of positive dipolar polarization, which in turn may be explained by the author's experiment on the diffusion of ions [14]. The author is considering the preparation of a further description of the "heat storm" which occurs most frequently at Taihoku in the afternoon of the summer season. Although at this place hygroscopic particles decrease greatly owing to the intense insolation during the daytime, the accomanying increase in wind-velocity raises the dust on the farms, increasing nuclei in the lowest atmosphere, and this is another fact which precludes the exclusive application of the conductivity-potential-gradient correlation. Wilson's dipole-theory is not exclusively invoked for explaining the diurnal minimum potential-gradient. On examining Brown's curves representing the diurnal variation of space-charge at the heights of one meter and of 15 meters, respectively, at Stanford, it is apparent that the space-charge is nearly homogeneous at least within the limits of one to 15 meters, and that there is a significant, though slight, relationship between the duration of inversion of space-charge and that of the minimum of the potential-gradient. Brown tried to explain this minimum by the inversion of space-charge. But in case the ionium-collector is suspended at a height of two meters, is it enough to take into account the distribution of space-charge up to a height of only 15 meters above the Earth's surface? Brown's explanation may hold for the variation in the earlier morning hours when convection is not yet vigorous, but does it still hold for the variation in the advanced morning hours when convection becomes sufficiently vigorous to extend up to the height of thunder-clouds? Brown has quoted in his treatise Clayton's survey showing the cumulus clouds at the Blue Hill Observatory and the depression in potential-gradient at Washington, D. C. The same relation exists at Taihoku. In consideration of the height of the cumulus cloud, it would appear that the correlation to which Clayton referred is rather to be accounted for by the "dipolar polarization." But it is not claimed that this theory is perfect and holds for every occasion. Reference is again made to Figure 4. The potential-gradient made an abrupt increase with sunrise on February 11, and then began to decrease until 9^h. The increase may be explained by the elevation of the center of space-charge caused by convection and the

decrease by the space-charge becoming homogeneous, as Brown states, since convection has now resumed its activity; both are phenomena in a comparatively low layer of the atmosphere.

(5) In the winter season, as the weather at Taihoku is generally found cloudy or drizzly, insolation is reduced, convection is depressed, and, as it is windy at that, mixing is vigorous. Thus electric polarization-effect is greatly hindered, and hence the disappearance of the morning maximum. For such reason the potential-gradient curve resembles a low hill with a gradual slope towards noon. After that the potential-gradient will not drop abruptly as is often the case in the summer night but will show low even values to the last.

These are probably the reasons why the potential-gradient at Taihoku is so much lower all through the year than at other places in the temperate zones. Though this hypothesis of the local variation cannot be regarded as having been subjected to severe test —since it is absolutely necessary, in determining the potential-gradient, to take into account all such factors as ion-spectrum and polar-conductivity, the extension of condensation-nuclei, and vertical flow of air due to convection or subsidence, etc.—it is sincerely hoped that it will be verified when sufficient data are made available through the results of additional electrical and meteorological observations and experiments.

In conclusion, the author expresses his sincere thanks to Professor Shiratori, Director of the Institute for his kindness, to Mr. Tatara, for his helpful consideration, and lastly but most sincerely to his senior Mr. N. Kanno for unfailing interest in the study and his constant encouragement and assistance.

References

[1] C. E. Deppermann, Terr. Mag., **36**, 231-237 (1931).
[2] K. Shiratori and S. Tatara, Jap. Ass. Adv. Sci., **10**, 359.
[3] R. A. Watson, London, Met. Office, Geophys. Mem., No. 38 (1928).
[4] J. G. Brown, Terr. Mag., **40**, 413-424 (1935).
[5] B. F. J. Schonland, Atmospheric electricity, p. 61 (1932).
[6] A. R. Hogg, Beitr. Geophysik, **43**, 359-378 (1935).
[7] C. Chree and R. E. Watson, Proc. R. Soc., A, **105**, 311-333 (1924).
[8] F. J. W. Whipple, Q. J. R. Met. Soc., **55**, 351-361 (1929).
[9] G. R. Wait, Terr. Mag., **36**, 111-131 (1931); G. R. Wait and O. W. Torreson, Terr. Mag., **40**, 425-430 (1935).
[10] E. C. Halliday, Terr. Mag., **38**, 37-53 (1933).
[11] H. L. Wright, Proc. Phys. Soc., **45**, 152-171 (1933).
[12] P. J. Nolan, Proc. R. Irish Acad., A. **41**, pp. 61-69 (1933).
[13] K. Shiratori, Proc. Fifth Pacific Sci. Cong., **3**, 1703-1718 (1934).
[14] K. Ogasahara, Mem. Sci Agric., Taihoku Imp. Univ., **18**, No. 6 (1936).
[15] K. Kähler, Met. Zs., **40**, 204-211 (1923).

The Institute of Meteorology and Geophysics,
The Taihoku Imperial University,
Taihoku, Nippon

COMMENT ON PROFESSOR OGASAHARA'S PAPER CONCERNING THE POTENTIAL-GRADIENT MEASUREMENTS AT TAIHOKU, FORMOSA

Before making comments on Professor Ogasahara's paper I should like to say that I had the opportunity of reading it in manuscript and, through various letters to Professor Ogasahara, took occasion to make the comments to him which are made below. His replies indicated how difficult it is to convey an attitude of helpful criticism by letter, a situation which too often arises when matters must be discussed by letter instead of by personal interview.

Professor Ogasahara evidently feels that his potential-gradient results indicate that atmospheric-electric and meteorological conditions are somewhat unusual at Taihoku. Chiefly, his average observed value of potential-gradient for two years of observation, about 30 volts per meter, is low and it is this low value for which he must account. However, as one sees from his paper, this low average is largely due to extremely small values in the night hours and particularly in the hours from midnight to sunrise. In August, for example, for a mean of several days of record in two years, the first six hours after midnight each averages zero volts per meter. In other months the early hours average only four or five volts per meter. One cannot help but wonder if insulation-leak may not have prevented correct functioning of his apparatus (reducing the negative as well as positive deflections on the records, for negative deflections are evidently encountered even in so-called fair weather) and so have prevented the values from departing much from zero. Insulation-difficulties were early recognized by Professor Ogasahara and much time was spent in trying to overcome them, but I am not convinced that they were entirely overcome. Maintaining good insulation on atmospheric-electric apparatus is an ever-present task, and it seems to me that one cannot make insulation-tests once every two weeks in a tropical locality like Taihoku, as Professor Ogasahara does, and assume safely that the insulation remains satisfactory in the interval. In fact, it has been my experience that, having tested insulation in the evening, records obtained a few hours later from midnight to sunrise have all too frequently had to be regarded with suspicion. Under difficult conditions, and the conditions at Taihoku must be regarded as difficult for potential-gradient work, one cannot assume even for a few hours that good insulation may be maintained, but must be ever ready to question the validity of the records.

Professor Ogasahara compares some of his results with those of Father Deppermann at Manila (Terr. Mag., **36**, 231-237, 1931) particularly with regard to the occurrence of periods of negative potential-gradient. However, when the sample record for each station is compared, the record for Manila does not suggest insulation-difficulty to me as does the record from Taihoku.

Professor Ogasahara attempts to account for the unusual character of his potential gradient values at Taihoku by a process which involves (1) formation of alternate strata of space-charge in the atmosphere through variations in diffusion-coefficients of small ions due to changes in temperature and content of water-vapor in the air and (2) displacement of one stratum of space-charge by another through circulation and subsidence. However, before the merits of this process are considered, it would seem desirable to establish beyond question that the potential-gradient data really have unusual character. Professor Ogasahara already feels strongly that the unusual character is real, of course, but I am hopeful that, as his observations continue, added tests will be applied to both apparatus and data to show unmistakably the validity of the measurements to those who are too far away to have personal contact with him and his work.

O. W. Torreson

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., January 11, 1940

REPORT ON WORK IN TERRESTRIAL MAGNETISM AND ELECTRICITY IN U.S.S.R. DURING 1936-1939[1]

By P. P. Lazarev, N. I. Leuschin, N. N. Nikolsky, N. V. Pushkov, and N. N. Trubyatchinsky

(I) *Observatories and institutions* The work in terrestrial magnetism and electricity is done at many observatories and institutions. The fields covered by the principal ones are as follows:

(1) *Institute of Theoretical Geophysics* of the Academy of Sciences of U.S.S.R., Moscow—Investigational and experimental work in magnetism of rocks and ionosphere

(2) *Institute of Physics* of the Academy of Sciences of U.S.S.R., Moscow—Cosmic rays

(3) *Institute of Energetics* of the Academy of Sciences of U.S.S.R., Moscow—Electricity of thunder-storms

(4) *Institute of Communication*, Moscow and Leningrad—Ionosphere, radio-wave propagation

(5) *Moscow Geophysical Observatory*—Maintenance of magnetic observatory at Nizhnedevitsk and atmospheric electricity

(6) *Central Geophysical Observatory*, Leningrad—Maintenance of magnetic and electric observatories at Sloutsk, magnetic survey and secular-variation research, geomagnetic charts, magnetic field-service, observations for determination of corrections on magnetic standards at observatories, ionosphere, radio-wave propagation, direction of atmospherics, electricity of the lower atmosphere, reduction of magnetic, auroral, and electric data, instrumental development

(7) *Arctic Institute*, Leningrad—Maintenance of five magnetic observatories (Tikhaya, Matochkin Shar, Dickson, Chelyuskin, Wellen), aurora, ionosphere, atmospheric electricity, earth-currents, reduction of magnetic, auroral, and electric data

(8) *Hydrographic Office of Northern Sea Route*, Leningrad—Magnetic survey, magnetic charts

(9) *Geological Institute*, Leningrad—Magnetic survey, magnetism of rocks

(10) *Institute of Metrology*, Leningrad—Research on magnetic standards, instrumental development

(11) *Institute of Experimental Meteorology*, Leningrad—Electricity of the lower atmosphere

(12) *Leningrad State University*—Geomagnetism and geoelectricity

(13) *Minsk, Geophysical Observatory*—Atmospheric electricity

(14) *Voronezh Geophysical Observatory*—Atmospheric electricity

(15) *Geophysical Observatory of the Academy of Sciences of Ukranian S.S.R.*—Magnetic survey

(16) *Kiev Geophysical Observatory*, Borispol near Kiev—Atmospheric electricity, earth-currents

[1]For report on work during 1931-35 see: N. V. Pushkov, Mitteilung über erdmagnetische und elektrische Arbeiten in der U.d.S.S.R. in den Jahren 1931-35, Terr. Mag., **40**, 393-399 (1935) also N. V. Rose, Der Zustand des Netzes der magnetischen Observatorien in der U.d.S.S.R. und weitere Perspektive seiner Entwickelung, Terr. Mag., **40**, 401-406 (1935).

(17) *Odessa, Geophysical Observatory*—Maintenance of magnetic observatory at Stepanovka
(18) *Rostov-on-Don Geophysical Observatory*—Atmospheric electricity
(19) *Institute of Safety of Mining Works*, Makeevka—Maintenance of magnetic observatory at Amvrossievka
(20) *Tbilisi Geophysical Observatory*—Maintenance of magnetic observatory at Dousheti, atmospheric electricity
(21) *Tbilisi Geophysical Institute*—Magnetic survey
(22) *Tashkent Geophysical Observatory*—Maintenance of magnetic observatory at Keles, atmospheric electricity
(23) *Cossakh State University, Alma-Ata*—Atmospheric electricity
(24) *Kazan (Zaimische) Magnetic Observatory*—Magnetic and atmospheric-electric observations
(25) *Sverdlovsk Geophysical Observatory*—Maintenance of magnetic observatory at Vissokaya Doubrava, atmospheric electricity
(26) *Urals Geological Trust*, Sverdlovsk—Magnetic survey
(27) *Tomsk Physical Technical Institute*—Ionosphere
(28) *Irkutsk Geophysical Observatory*—Maintenance of magnetic observatory at Zoui
(29) *Vladivostok Geophysical Observatory*—Maintenance of magnetic observatory at Mai-Toon
(30) *Yakutsk Geophysical Observatory*—Magnetic observations
(31) *Kolymsk Geophysical Observatory*—Magnetic observations at Srednikan

The following short review shows the extent of work which has been done during the last three years.

(II) *The general magnetic survey of U.S.S.R.*—During 1936-39 the magnetic survey was continued chiefly in regions in the north of U.S.S.R. not readily accessible. The absolute determinations were made along the principal roads and rivers at distances between stations of about 20 to 25 km. In southern regions of the Union the homogeneous survey was done at average distances between stations of about 20 km. As a rule the measurements of vertical force with field-balances were taken between the points where absolute determinations were made.

The Section of Magnetic Survey and Magnetic Cartography of the Central Geophysical Observatory made determinations during 1936-38 of D, I, and H at 3211 stations, of Z at 30823 stations. In addition the Hydrographic Office of the Northern Sea Route made magnetic determinations at nearly 500 stations on the shore, ice, and islands of the Arctic Ocean. The observations of E. K. Fedorov during the drift to the North Pole and those of D. S. Fomenko and V. Kh. Bouinitsky during the drift of the icebreaker *Sedov* are here taken into consideration. Good progress has been made in the reduction of accumulated observational data. A set of magnetic charts of U.S.S.R. for the epoch 1935.5 and several of the regional charts showing magnetic anomalies have already been constructed on the basis of these data.

A new plan for continuing the magnetic survey in regions not yet covered is being made.

(III) *The study of the secular variation*—The total number of repeat-stations in U.S.S.R. is 270. In 1936 repeat-observations were made at 100 stations, in 1937 at 67, in 1938 at 101. It is anticipated that 80

stations will be occupied in 1939. The isoporic charts of all the magnetic elements for the epoch 1930-1935 were constructed.

(IV) *Magnetic observatories*—During the past three years there were in continuous operation seventeen permanent magnetic observatories as listed in Table 1.

TABLE 1—*Magnetic observatories of U.S.S.R.*

·).	Observatory	Latitude, north		Longitude, east		Work began	Publications[2] during 1936-1938
		°	′	°	′		
1	Tikhaya	80	20	52	48	1931	1932, 1933, 1934, 1935, (1936)
2	Chelyuskin	77	17	104	17	1934	1935, (1936)
3	Dickson	73	30	80	25	1932	1932, 1933, 1934, 1935, (1936)
4	Matochkin Shar[1]	73	16	56	24	1923	1932, 1933, 1934
5	Wellen	60	10	190	09	1933	1935
6	Yakutsk	62	01	129	43	1932	1932-1933
7	Srednikan	63	51	118	30	1935	
8	Sloutsk	59	41	30	29	1878	1934, 1935, 1936
9	Vissokaya Doubrava	56	44	61	04	1930	1932, 1933, (1936)
0	Zaimische	55	50	48	51	1909	1932, 1933, (1936)
1	Zoui	52	28	104	02	1914	1932, 1933, (1936)
2	Nizhnedevitsk	51	33	38	21	1934	(1936)
3	Amvrossievka (Makeevka)	47	53	38	29	1939	
4	Stepanovka (Odessa)	46	47	30	53	1936	(1936)
5	Mai-Toon	43	15	132	20	1933	(1936)
6	Dousheti (Karsani)	42	05	44	42	1936	(1932, 1933)
7	Keles (Tashkent)	41	20	69	18	1936	

[1]Registration was interrupted from March 20, 1935 to February 25, 1936.
[2]Parentheses indicate that hourly values are in print.

Because of artificial disturbances the magnetic observations at Kandalasksha were discontinued and three observatories (Odessa, Tashkent, and Karsani) were transferred to new sites at Stepanovka, Keles, and Dousheti. The observatory Matochkin Shar, destroyed by fire in 1935, was completely rebuilt in 1936. Temporary magnetic stations were organized to study the effect of the solar eclipse on the Earth's magnetic field, and the magnetic variations at Kursk magnetic anomaly and on Jekman islands in the arctic region.

The observatories of Dickson, Zoui, Vissokaya Doubrava, Nizhnedevitsk, Zaimische, and Keles were equipped with auxiliary control-magnetographs and the observatories of Dickson, Wellen, Mai-Toon, and Keles were provided with new magnetic theodolites. As compared with the preceding three years, some progress was made in printing and preparation of the hourly values for publication. Many observatories are publishing their ten-day summaries of magnetic data. The Sloutsk Magnetic Observatory is publishing ten-day summaries of "cosmic data" and collected volumes on terrestrial magnetism and electricity. (Inform. Sborn. Zem. Mag. Electr.). These volumes contain original papers, translations, notes, reviews, and abstracts, annual summaries of solar and magnetic-activity data, and lists of recent publications.

(V) *Earth-currents*—Since 1938 the north-south and west-east components of earth-currents were recorded continuously at Borispol.

The distance between the electrodes is one km for both components. The registration of earth-currents and rates of changes of the vertical component of the Earth's magnetic field were made with a large horizontal coil and a galvanometer-system at Cape Vykhodnoi, Novaya Zemlya, during 1937-1938.

(VI) *Atmospheric electricity*—During the past three years continuous observations of atmospheric electricity were made at Tikhaya, Chelyuskin, Sloutsk, Kounzevo (near Moscow), Borispol, Minsk, Voronezh, Sverdlovsk, Rostov-on-Don, Tashkent, Alma-Ata, the Glacier of Fedchenko in the Pamirs, and at one point on the Tyan-Shan Mountains. The routine work includes observations of the conductivity and potential-gradient.

(VII) *Ionosphere*—Ionosphere-stations are in operation at Tikhaya, Tomsk, and Sloutsk. They have manual multifrequency equipment. The automatic multifrequency recording equipment is now installed at Sloutsk.

(VIII) *Auroral observations*—The Sloutsk Magnetic Observatory and the Arctic Institute organized visual auroral observations at nearly 200 meteorological stations. The details observed and recorded include position, intensity, color of different auroral forms, and principal changes that occur during a display.

(IX) *Magnetic field-service*—Magnetic information was broadcast daily at Sverdlovsk, Tbilisi, and Tashkent. The Sloutsk Magnetic Observatory furnished every four hours magnetic information to the principal communication-services. In some cases this information was given every hour. The magnetic observatories of Sloutsk, Zaimische, Vissokaya Doubrava, Stepanovka, Zoui, Mai-Toon, Keles, and Dousheti characterized magnetic activity of each quarter-day on the scale 0.0, 0.5, 1.0, 1.5, or 2.0. The Sloutsk Magnetic Observatory distributed daily the so-called Union magnetic character-figures based on this scheme. The stations at Yakoutsk, Mai-Toon, Zoui, Vissokaya Doubrava, Zaimische, Nishnedevitsk, Stepanovka, Dousheti, and Keles issued ten-day summaries of magnetic data. They include daily and hourly magnetic character-figures, daily ranges of the magnetic elements, and description of magnetic storms. The ten-day summaries of cosmic data issued by the Sloutsk Magnetic Observatory include magnetic data at Sloutsk and at other observatories, sunspot-numbers from observations of the Tashkent Astronomical Observatory, ionospheric data from the Tomsk ionosphere-station, times of occurrence of aurora from observations of the meteorological stations, and other information. At the Sloutsk and Nizhnedevitsk magnetic observatories solar observations are made and magnetic disturbances are forecast.

(X) *Investigational and instrumental development: Permanent field* - Academician P. P. Lazarev and his collaborators O. N. Althausen, G. A. Kalashnikov, G. N. Petrova, and M. S. Zykeev are studying the magnetic properties of rocks for the determinations of the Earth's magnetic field and secular changes in past geological ages. B. P. Weinberg, N. I. Loktev, and V. P. Shibaev examined in a set of papers (not all of which have been published) such questions as the methods of separation of the normal field and anomalies, the correlation in distribution of the magnetic elements and their secular changes, and the relation between the

anomalies of different elements. They are also continuing to collect magnetic data for the world magnetic catalogue.

G. D. Kalinin developed a new method of mathematical treatment of Bauer's residual field and T. N. Rose examined the possible change of this field. Many authors discussed the methods of geological interpretation of magnetic data.

Magnetic variations—N. P. Benkova completed a spherical harmonic analysis of S_q-variation using the data for the international quiet days of the summer of 1933 from 46 observatories distributed over the entire Earth. K. G. Bronshtein, P. I. Gussev, and B. M. Yanovsky made the comparison of magnetic variations observed at the Kursk magnetic anomaly with those observed in the normal field at Nizhnedevitsk.

Magnetic disturbances—P. I. Gussev proposed a new explanation of relationship between sunspots and magnetic disturbances permitting the prediction of magnetic disturbances. Tests of his hypothesis are under way. N. V. Abramova and N. V. Pushkov examined the secular, annual, and diurnal variations of sudden commencements of magnetic storms, according to data from nine observatories. V. I. Afanassieva studied the annual and diurnal variations of magnetic bays based on records of the Zaimische Observatory. A catalogue of magnetic storms recorded at Sloutsk Observatory, beginning with 1878, was compiled.

Magnetic activity—G. D. Kalinin computed the *u*-measure of magnetic activity for 1933 using the data from observatories in both low and high latitudes and determined therefrom the radius of equatorial ring-currents. The diurnal variation of magnetic activity was determined for some observatories by M. A. Lipina and A. P. Nikolsky, N. N. Russnachenko, and A. I. Pogulyaeva extended the magnetic classification of Greenwich days at Sloutsk to cover the period 1869-1905.

Aurora—Using the observations of meteorological stations N. S. Brunkovskaya and N. V. Pushkov constructed a chart of distribution of auroras in the Soviet arctic region during the Second International Polar Year. On the basis of the observations at these stations they studied also the correlation between magnetic and auroral activity. The correlation of magnetic and auroral activity was also discussed by N. V. Abramova, N. V. Brunkovskaya, N. V. Pushkov, and S. L. Issaev using magnetic and auroral observations at Tikhaya and Chelyuskin.

Ionosphere and radio-wave propagation—The results of ionospheric observations obtained at Tomsk were discussed by N. D. Boulatov, N. N. Kessenikh, and A. I. Likhachev. B. F. Arkhangelsky and N. P. Pabo examined the radio-wave propagation and atmospherics in high latitudes. The relation between the radio-wave propagation and magnetic activity was examined by N. N. Leushin and E. S. Merkoulova.

Atmospheric electricity—The electric state of the lower atmosphere and its relations with weather-phenomena were studied by R. A. Allik, N. I. Leushin, E. S. Merkoulova, V. I. Pogodin, V. I. Gerasimenko, and others.

Effects of electrification of railways—The effects of electrification of railways on magnetic and earth-current observations were investigated by A. F. Ogoursky, N. N. Russnachenko, and V. F. Shelting.

Instrumental development—A portable magnetograph was constructed. It consists of *D*-, *H*-, *Z*-variometers and a special recorder placed in a chamber 90 by 40 by 60 cm with a total weight of about 13 kg. The

recorder furnished a normal registration without interruption during ten days. Photographic registration and eye-readings may be made simultaneously.

The variometers are compensated by the new method of temperature-compensation proposed by B. M. Yanovsky. The magnetic theodolites of new form proposed by K. G. Bronshtein were constructed and used for field-measurements. In these theodolites H is determined by torsion of the fiber and I by Lamont's method. A new small earth-inductor with iron core designed by N. N. Trubyatchinsky is now being tested under field-conditions. A new type of H and Z field-balances proposed by D. S. Mikov is now being constructed. A. A. Logachev and G. A. Kalashnikov developed methods of altitude-measurements. N. S. Brounkovskaya and G. I. Kasakov proposed new methods of recording and indicating the beginning of magnetic storms.

New instruments for atmospheric-electric observations were also proposed by M. N. Gerassimova, V. F. Litvinov, and E. A. Chernyavsky.

Conferences—For the discussion of reports and the coordination of researches one ionospheric conference and two geomagnetic conferences were held.

[The above is an abstract of a report made for U.S.S.R. to the Washington Assembly (September 1939) of the International Union of Geodesy and Geophysics. This report, with 183 references to published papers, will be published in full in the forthcoming volume "Transactions of Washington Meeting" by the Association of Terrestrial Magnetism and Electricity.]

Central Geophysical Observatory,
Leningrad, U.S.S.R.

AURORAS, RADIO FIELD-STRENGTHS, AND RECENT SOLAR ACTIVITY

Harlan T. Stetson

Of the many suspected relationships between observable terrestrial phenomena and solar activity, as marked by sunspots, those longest recognized are the variations in the characteristics of the Earth's magnetic field and the occurrences of auroras. The advent of radio communication in recent years has opened up a new field for the investigation of conditions of ionization in the Earth's upper atmosphere and affords a new source of observational data for the study of solar-terrestrial relationships. The simultaneous occurrence of radio fade-outs, solar eruptions, and violent changes in the Earth's magnetic field have received wide attention. The more general changes in radio transmission with the occurrences of auroras, and geomagnetic fluctuations accompanying increased sunspottedness are of a more gradual nature and probably follow in a somewhat different category from phenomena of the eruptive fade-out.

It was early recognized that auroral displays must be associated with ionization of the upper air at high altitudes, and various hypotheses have been advanced to account for increased ionization during periods of major solar activity. Whatever may be the differences of opinion in regard to the mechanism connecting sunspots with auroral displays, there is some evidence that auroral phenomena are intimately associated with sunspots themselves, rather than with a general state of radiation-emission accompanying the solar cycle. The experimental and observational studies of Birkeland [see 1 of "References" at end of paper] and of Störmer [2], reproducing so remarkably typical auroral forms by tracing the trajectories of charged particles entering the magnetic field of the Earth, make it appear somewhat difficult to reject altogether some sort of a corpuscular hypothesis.

There are astrophysical objections to the emission of electrons from the solar surface that cannot be lightly set aside. Yet Swann [3] points out a possible mechanism whereby the magnetic field of sunspots may propel electrons earthwards, and more recently Vallarta [4], in considering the effect of solar activity upon variations in the intensity of cosmic rays, has given further consideration to the emission of charged particles from sunspot-cones. If one assumes the Sun to possess a permanent magnetic field, it would not ordinarily appear possible for charged particles of any reasonable energy to leave the Sun except near the poles where exit may take place through Störmer's forbidden region. Since, however, observations show that sunspots produce local magnetic fields of several thousand gauss, it appears possible that the toroidal shell, surrounding the Sun, may be sufficiently distorted to allow the ejection of charged particles through the otherwise forbidden zone. Vallarta [5] points out that, with proper initial conditions, the paths of such ejected particles may approach principal periodic orbits in the Earth's magnetic field by following along outer, nearly asymptotic, paths. Grotrian [6] considers the possibility that particles associated with solar atmospheric eruptions, containing relatively high charges when escaping, would travel at velocities far slower than electron-speeds, velocities of such particles being of the order of magnitude of about 2000 kilometers per second. The ionizing energy of such particles, reaching the Earth from the Sun, would be derived in a large measure,

therefore, from the magnitude of the electric charge, thus offsetting the lower velocity. On the assumption of velocities of this order of magnitude, a delay of 24 to 36 hours would be incurred, while such particles traverse the distance from the Sun to the Earth.

It was thought that a study of the times of occurrences of bright auroral displays and the degree of sunspottedness for a period adjacent to the auroral dates during recent years, together with radio-transmission conditions during a like period, might afford material pertinent to the determination of any sequence in these related events, if such a sequence should exist.

On examination of the table of auroras, given by Chree [7] in the Encyclopedia Britannica, listing conspicuous displays from 1749 to 1877, a lag of a year or more may in general be noted between the peak of the Wolfer sunspot-numbers and the year of the maximum in the occurrences of aurora polaris. In a recent article [8] I presented qualitative results of an examination of the auroral records of the Blue Hill Observatory at Milton, Massachusetts, placed at my disposal through the courtesy of the Director, Dr. C. F. Brooks. The Blue Hill list comprises some 280 observations from the founding of the Observatory in 1885 through the year 1939. The smoothed curve in the above-mentioned article indicated a lag of about one year between the date of sunspot-maximum and the date of the maximum auroral frequency. In this study only auroras of brightnesses estimated as 1 and 2 on a scale of zero to 2 were considered and the frequency was weighted in accordance with the estimated brightness. In Figure 1 separate repre-

FIG. 1—NUMBER OF AURORAL OCCURRENCES

sentations have been made for auroral intensities 1 and 2, arranged with respect to years before and years after the year of maximum sunspot-numbers. A comparison of the two representations shows a pronounced lag of about two years in the case of the brighter auroras. The lag seems evident in the representation for the less bright auroras, although in this case it is less pronounced. An extraordinary number of auroras occurring in 1892 accounts for the unusually high point one year before the sunspot-maximum in the half of Figure 1 depicting auroras of brightness 1. As pointed out elsewhere [8] it is suggested that the lag

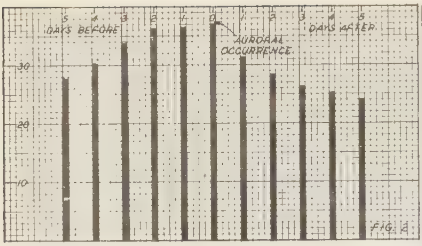
between the occurrences of bright auroras and high sunspot-numbers may be due to the fact that disturbances on the Sun at low solar latitudes are more effective in producing displays of the polar light than comparable solar disturbances at higher latitudes.

In a recent study of Blue Hill auroras by H. H. Clayton [9] evidence is presented that sunspots associated with auroral displays average greater area when appearing at high latitudes on the Sun's disk than do spots at low latitudes accompanying auroral occurrences. Such an inference seems consistent with the hypothesis suggested. An analysis of areas of sunspots with respect to the central meridian, made by Mr. Clayton, indicated also that disturbed regions on the Sun were on the average one to two days past the central meridian when the auroral curve, based on the Blue Hill observations, reached its peak.

On the assumption that sunspots near the central zone would be associated more often with the emission of charged particles directed earthwards, I have plotted (Fig. 2) the Zürich sunspot-numbers in the central zone of the Sun from five days before to five days after all the 71 brighter auroral occurrences available from the Blue Hill list from 1917 to 1939. Plotting the sunspot-numbers for the whole disk and for the central zone for the same period yielded in both cases substantially the same result. There appears therefore to be no particular argument from sunspot-numbers alone in favor of centralized sunspots being more intimately associated with auroral phenomena.

Even granting the validity of the hypothesis of the ejection of particles from sunspot-centers, if such particles were other than electrically neutral, the perturbations of their paths by the magnetic field of the Sun, together with those introduced by the Earth's magnetic field, could so materially alter the trajectories of the particles as to confuse any direct correlation between the position of a given sunspot and associated auroral phenomena. If we take the sunspot-numbers for the whole disk or for the central zone, a lag of one day appears to exist between the epoch of observed sunspot-data for a given day and the time of auroral occurrences. There is, of course, an uncertainty of a fraction of a day that may exist between the observation of the sunspot-number and the witnessing of auroras, which obviously must be observed in darkness. However, since the final Wolfer sunspot-numbers are based upon observations in all longitudes, it would appear that there still exists a real lag between the times of major solar activity and the major occurrences of auroras. This is consistent with the anticipated delay in ionization from the ejection of particles of low velocity emitted from sunspots as suggested by Grotrian [6]. It is perhaps conceivable that the elapsed time between solar disturbances as marked by sunspot-activity and the occurrences of auroras may be partly due to the time required for building up an excess degree of ionization in the Earth's atmosphere following any increase in the ionizing agent brought about by sola disturbances, whatever the mechanism involved.

It is here that we may turn to measurements of radio transmission for new data, since the behavior of radio transmission is known to be intimately associated with the ionization of those same regions of the Earth's upper atmosphere in which auroral phenomena most often occur. It appears of interest, therefore, to record the result of recent



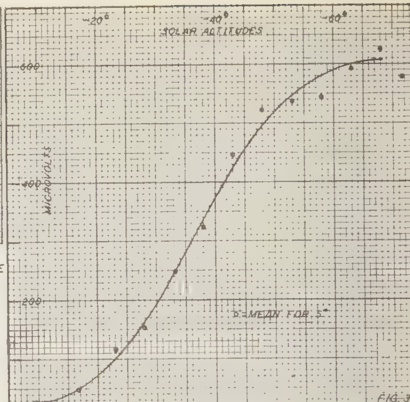


FIG. 2—CENTRAL-ZONE SUNSPOT-NUMBERS, FIVE DAYS BEFORE AND AFTER AN AURORAL OCCURRENCE, BRIGHTNESSES 1 AND 2, BLUE HILL, MASSACHUSETTS, 1917 TO 1939

FIG. 3—VARIATION OF FIELD-STRENGTH WITH DEPRESSION OF SUN BELOW HORIZON; BASED ON 8192 OBSERVATIONS (HALF-HOUR PERIODS) WBBM RECORD AT WABAN, MASSACHUSETTS, NOVEMBER 1935 THROUGH JANUARY 1938

studies of changes in conditions for radio transmission before and after the occurrences of auroral phenomena.

The long series of measurements of radio field-intensities of WBBM, Chicago, received in the vicinity of Boston, and now being conducted at our suburban laboratory at Needham, offers sufficient material for a fair comparison between disturbances at the altitudes of auroral levels and changes in ionization in the strata of the ionosphere from which electromagnetic waves of broadcast frequencies are returned to the Earth. Our data of field-strengths of WBBM's carrier-wave at a frequency of 770 kilocycles comprise over 100,000 measurements, covering ten-minute intervals of night-to-night continuous recordings. Utilizing the radio data from 1930 through 1939, Table 1 was prepared exhibiting the average all-night variations in field-strengths as have occurred from six days before to six days after 32 occurrences of the brighter auroral displays during the decade.*

It is necessary to digress at this point to emphasize that, in utilizing radio field-strength measurements, care had to be taken at the outset to make due allowance for the early evening variations due to the twilight effect on the ionosphere. This twilight effect has not only a diurnal but a seasonal component, and depends upon the depressed altitude of the Sun below the horizon of the transmission-path.

To adopt an arbitrary standard for reduction, the average increase of field-strengths over many hundreds of nights was plotted against negative altitudes of the Sun referred to the horizon defined by the latitude and longitude of Boston. The gain of field-strength versus decreasing solar altitudes is exhibited in Figure 3. For a fiducial point to which any night's field-measurement could be corrected for the daylight and darkness effect so that a given period of observations could be reduced to some arbitrary standard, the base adopted has been the average field-strength represented on this curve for the condition obtainable when the Sun has a depression of 30° below the horizon at

*The cooperation of station WBBM provided necessary information at the transmitting end for the interpretation of the field-strengths measured. The data for 1930 to 1934, included in this study, were made possible through the cooperation of Professor G. W. Kenrick in maintaining the series during that interval. The relative values given in Table 1 are in microvolts. Preliminary values for the effective height of the antennas used so closely approximate one meter that the tabular values may be roughly taken as representing microvolts per meter.

TABLE 1—*Mean of nightly field-strengths (corrected) of WBBM, Chicago, from six days before to six days after date of auroral occurrences of brightnesses 1 and 2*

Date	Days before						Auroral occurrence	Days after					
	6	5	4	3	2	1	0	1	2	3	4	5	6
1930													
Sep. 18	262	274	325	102	180	273	16	8	61	21	156	37	23
Oct. 1	31	28	268	100	34	19	21	12	4	26	34	30	49
1931													
Oct. 12	112	59	219	182	320	82	65	140	188	145	187	169	81
1932													
Apr. 1	106	113	35	30	28		75	72	39	44	86	93	36
Apr. 23	71	82	130	134	130	170	149	63	50	203	241	99	95
1936													
Apr. 17									7	5	2	9	
Oct. 16	217	219	542				61	45	56	152	62	228	497
1937													
Apr. 26	606	719	569	703	27	133	1	3	2	9	126	196	130
Sep. 10	286	146	239	257	273	280					175	108	322
Oct. 3	423	243	447	13	24	121	9	44	12	13	18	119	87
1938													
Jan. 25	24	12	58	22	12	60	33	12	17	62	1	19	21
Mar. 22	155	147	238	490	467	309	23	5	13	5	15	56	23
Mar. 23	147	238	490	467	309	23	5	13	5	15	56	23	22
Apr. 16	118	84	437	67	102	3	135	10		17	36	66	64
May 3	45	79	158	29	51	82	57	53	74	83	32	88	303
Sep. 28										108	62	35	76
Oct. 7	102	62	35	76	18	98	68	2	6	9	1	11	66
Oct. 27	86	86	227	58	73	77	6	7	4	10	64	31	27
Dec. 2	38	33	271	9	257	281	29	6	15	5	77	184	60
Dec. 3	33	271	9	257	281	29	6	15	5	77	184	60	181
1939													
Feb. 24	158	165	168	327	490	431	5	1	1	9	1	9	56
Mar. 28	117	51	54	172	63	39	3				24	42	29
Apr. 23	3	85	19	68	28	30	15	3	74	19	35	28	140
May 16			7	129	180	285	318	237	162	170	351	249	393
June 17	573	982	159	4	292	5	279	177	143	465	274	132	343
Aug. 11	252	159	252	567	207	130	109	69	45	91	81		62
Aug. 12	159	252	567	207	130	109	69	45	91	81		62	16
Aug. 22		62	16	18	27	74	14	21	63		14		24
Sep. 19	31	73	35	32	50	27		33	40	20	17	26	47
Sep. 20	73	35	32	50	27		33	40	20	17	26	47	74
Oct. 13	10	28	26	2	20	22		12	17	14	11	8	16
Oct. 14	28	26	2	20	22		12	17	14	11	8	16	11
Mean	152	165	201	158	142	122	59.8	41.6	43.8	65.7	79.2	76.0	108

Boston. Field-strengths determined at such hours of the night, or at such seasons of the year, that occurred when the Sun was at a less negative altitude than this, were augmented by the percentage shown to be necessary on this reduction-curve in order to attain the field-strength that would have been evident under similar conditions for a standard

depression of the Sun of 30° below the horizon. Field-strength measurements occurring at late hours of the night, or at earlier hours during the winter season when the Sun was more than 30° below the horizon, were diminished proportionately in order to reduce the observations to the standard conditions adopted. One cannot overemphasize the importance of such a procedure before attempting any statistical study of field-strength measurements that may lead to correlations with cosmic phenomena of other than a diurnal or seasonal nature.

Specifically, the curve in Figure 3, showing increasing field-strengths with negative altitudes of the Sun, is based upon the values of over 8000 half-hourly means of observations of the measurement of field-strengths made between November, 1935, and January, 1938. The mean observed field-strength was first tabulated for every degree of depressed solar altitude from $-10°$ to $-72°$. The average value of the field-strengths of five successive degrees was then taken as the basis for the curve. Each dot on the curve in Figure 3, therefore, represents the values thus obtained at approximately 5°-intervals. The number of observations entering into each point was not less than 250 half-hourly means for the smaller negative altitudes of the Sun. Points on the curve representing negative altitudes from $-25°$ to $-70°$ comprise from 500 to 1000 half-hourly means each. The smoothed curve, therefore, appears to be fairly representative of the expected increase in field-strengths, as the Sun sinks below the horizon from shortly after sundown to midnight. Since the changing declination of the Sun enters into the calculation of the negative altitudes, it will be observed that the curve takes into account both diurnal and seasonal effects, due to the Sun's change in declination. With this system of corrections clearly in mind we may proceed to an examination of the results with respect to the occurrences of auroras (Table 1).

In Figure 4 we have an exhibit of the mean nightly field-strengths, corrected as described above, showing the average values in microvolts at the receiver of the intensity of WBBM's carrier-wave for all available data from 1930 through 1939, arranged in sequence from six days before to six days after the date of auroral occurrences during the same years. In choosing auroral dates from the Blue Hill list, all questionable or suspected auroras were eliminated. The Blue Hill list estimates auroral intensities on a scale of 0, 1, and 2, the value zero representing the faint auroras and 2 the brightest auroral displays. The data comprising Figure 4 were, therefore, limited to occurrences of only the brighter auroras estimated to be of intensities greater than zero. Figure 5 shows the relative sunspot-numbers for the whole disk covering the same identical dates.

These figures show that the minimum field-intensities were received, on the average, from one day to two days after the occurrences of the auroras. In Figure 4 it will be seen that very large field-strengths occur four days before the date of bright auroral occurrences, and yield average intensities of 200 microvolts. Field-intensity drops rapidly with the approach of the auroral date and falls to a minimum one day following the date of the bright auroras.

Taking the average of all the nightly field-strengths of a typical year, 1938, the yearly average yielded a value of 113.2 microvolts. We

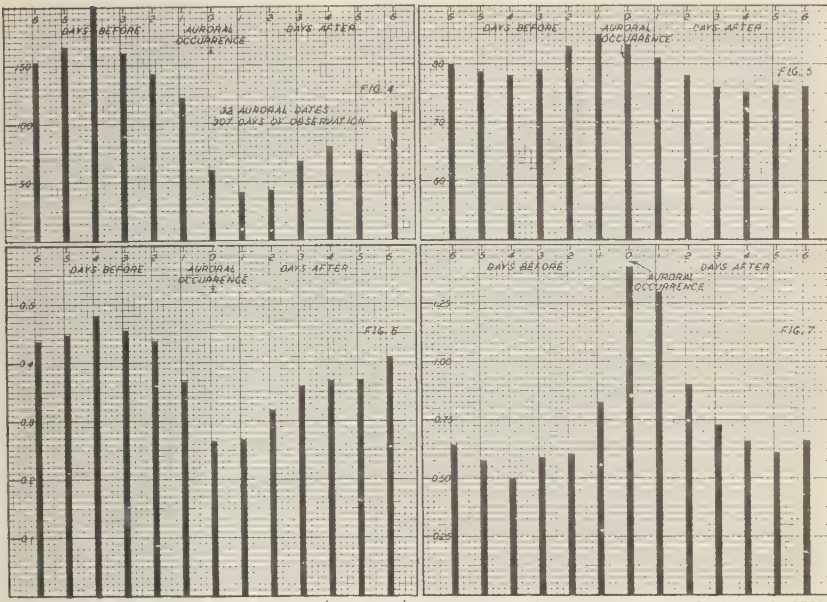


FIG. 4—MEAN OF NIGHTLY FIELD-STRENGTHS (CORRECTED), WBBM, CHICAGO, FROM SIX DAYS BEFORE TO SIX DAYS AFTER DATE OF BRIGHT AURORAL OCCURRENCES (BRIGHTNESSES 1 AND 2), 1930-39 FIG. 5—MEAN OF RELATIVE NUMBERS FOR THE DISK OF WHOLE SUN, 1930-39 FIG. 6—TRANSMISSION-INDEX FOR HIGH FREQUENCIES (RECIPROCAL OF TRANSMISSION-DISTURBANCE NUMBERS), 1930-39 FIG. 7—MAGNETIC CHARACTER-NUMBER AND AURORAL OCCURRENCES, 1930-39

cannot go far wrong, therefore, in assuming normal field-strength as of about this value. It will be seen, then, from Figure 4 that from at least six days before to one day before the dates of auroral occurrences the field-strength of WBBM in the vicinity of Boston was abnormally high. From shortly before the dates of the auroral occurrences to five days after the field-strengths were markedly subnormal. In taking the average field strength the dates of auroras were purposely not excluded. This fact, however, could not materially affect the mean value since it will be noted from the graph that the excess in field-intensities preceding auroral occurrences is offset by a corresponding deficiency for the days following auroral occurrences.

Since WBBM operates in the broadcast band on a frequency of 770 kilocycles, radio transmission is turned back from the *E*-layer which maintains a level of about 100 km. It would appear, therefore, that while Figure 5 indicates that changes in atmospheric ionization attending sunspot-activity is on the average followed a day later by peak-performances in auroral displays, another day elapses before the ionization of the *E*-layer is so affected as to produce minimum field-strengths over the transmission-path from Chicago to Boston. Since, if there is a direct solar effect, one might well expect *E*-layer disturbances would follow changes in the ionization of the higher *F*-region, observational data of transmission in the *F*-region might be hoped to yield an intermediate lag.

No daily figures for field-intensities in the *F*-region, as such, were available for comparison, but fortunately through the courtesy of the Bell Telephone Laboratories we have long records of transmission-disturbance figures of transoceanic communication. An investigation of these transmission-disturbance figures was therefore undertaken to see if the times of maximum disturbance so recorded would represent a delay following solar activity that is intermediate between the occurrence of auroras and of the minimum of our measured field-strengths resulting from broadcast transmission via the *E*-layer.

Before considering the results of this part of the investigation, a word of explanation is appropriate in regard to the way in which T-D (transmission-disturbance) numbers are derived.

Transatlantic short-wave field-intensities, including transmission-signals on all used frequencies, are averaged for each day at the Bell Telephone Laboratories. The amount that this average is below the average for ten preceding undisturbed days is then obtained. The T-D figures are based on an arbitrary scale of 1 to 5, numbers increasing as the depression for any given day falls below the average for the ten preceding undisturbed days. An evaluation of this arbitrary scale shows that a T-D value of 5 corresponds to a depression of 27.5 decibels, where unity on the T-D scale is taken as representing zero-depression. A linear relationship exists between the T-D value and the corresponding depression in decibels. For a criterion in choosing the ten undisturbed preceding days a value for the day of T-D equal to, or less than 1.5, was set. Such a criterion was adopted in preference to choosing days defined by low magnetic character-numbers because of the delay necessitated in obtaining magnetic character-figures. I am indebted to Dr. R. K. Potter of the Bell Telephone Laboratories for the information in regard to the method there used in assigning the T-D numbers.

All available data of the transmission-disturbance figures from 1930 through 1939 were therefore examined, and the data were treated precisely as we treated the data for field-intensity measurements. To obtain an index for transmission-conditions in the *F*-region that might be compared with our *E*-layer recordings I have taken the reciprocal of the T-D numbers as an index of transmission. Figure 6 is a graphical representation of the index of transmission so defined and based upon the Bell Laboratory T-D numbers for a period extending from six days before to six days after the occurrence of the brighter auroras of estimated brightnesses greater than zero. It will be observed that the lowest values occur on the day of auroral occurrence and on the day following. This suggests a half-day lag between the date of auroral displays and the minimum for the transmission-index in transoceanic communication. Since the wave-lengths utilized lie in the high-frequency band of 9 to 16 megacycles, we are here obviously considering phenomena accompanying transmission by way of the *F*-layers. Since the one-half-day lag here noted lies intermediate between the auroral occurrences and the lag in minimum field-strengths measured in the broadcast band from our own records, we have in these results a suggested confirmation of a sequence of observational phenomena from solar activity through auroral discharges to radio disturbances, affecting first the *F*- and then the *E*-layers. This is consistent with generalized statements recently made by Berkner, Wells, and Seaton [10] concerning effects of ionospheric disturbances on radio transmission.

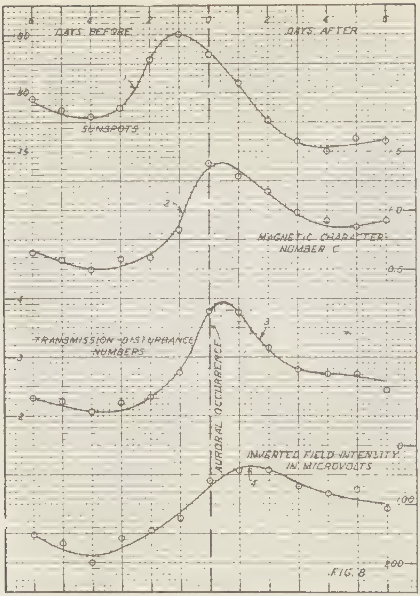
Since presumably a major factor in geomagnetic disturbances is a change in the ionic or electronic concentration in the ionized layers of the atmosphere, it appeared desirable to compare similarly the values of the magnetic character-figure *C* with respect to the same auroral dates; *C* was taken from lists published in this JOURNAL [11]. The mean character-figures were averaged as in the previous analysis for from six days before to six days after the date of the maximum occurrences of the bright auroras taken from the Blue Hill list. Figure 7 is a graphical representation of the result. It will be observed that the two highest values of *C* occur on the day following the date of auroral occurrences. This would appear to indicate that the disturbances in the ionized atmosphere representing the principal external factor in the variation of the Earth's magnetic field arise slightly preceding or concomitantly with disturbances in the *F*-layer.

Table 2 gives a brief summary of the relationships of the various

TABLE 2—*Summary of mean sunspot-numbers, transmission-disturbance numbers, radio field-strengths, and magnetic character-figures, 1930-1939*

Days from auroras	Sunspot-numbers	T-D numbers	Radio field-strengths	Character-figure *C*
−6	79.5	2.30	152	0.64
−5	78.5	2.25	165	0.57
−4	77.9	2.09	201	0.49
−3	78.7	2.21	158	0.58
−2	82.9	2.31	142	0.60
−1	85.0	2.75	122	0.83
0	83.3	3.79	59	1.40
+1	80.8	3.77	41	1.29
+2	77.6	3.15	43	0.90
+3	75.9	2.80	65	0.73
+4	75.0	2.71	79	0.66
+5	76.2	2.71	76	0.61
+6	75.9	2.45	108	0.66

terrestrial effects for the decade 1930 through 1939, together with the sunspot-numbers for each day from six days preceding until six days following the day of auroral occurrences. Figure 8 summarizes the interrelationship of these cosmic effects: Curve 1 shows the Zürich sunspot-numbers; Curve 2 represents the magnetic character-figures; Curve 3 represents the averaged T-D (transmission-disturbance) numbers from the Bell Telephone records; Curve 4 represents the relative field-intensities in microvolts of WBBM, as recorded in the vicinity of Boston—the values are plotted inverted to facilitate comparison. The epoch of auroral occurrence is indicated by the vertical line designated O. It will be seen that the maximum of the sunspot-numbers precedes the curve of auroral occurrences by about one day. Next in order comes the maximum of the curve representing magnetic character *C* closely matched by the maximum of the curve of transmission-disturbances involving the *F*-layer. These peaks occur close to the day of auroral dates. The minimum intensity of field-strengths in the broadcast band involving the *E*-layer, as represented in Curve 4, is about one and one-half days.



It is to be hoped that as our knowledge of the ionosphere increases and more observational data become available, theoretical developments may make it possible to derive a relationship between field-strengths, frequencies, and electron-density for a given region of the ionosphere. When, and if such becomes possible, we may hope to gain some idea of the change of energy necessary to produce the given changes in field-intensities observed.

References

[1] Kr. Birkeland, Norwegian Aurora Polaris Expedition 1902-03, Christiania, **1**, Part 1, 39-315 (1908) and Part 2, 319-551 (1913).
[2] C. Störmer, Terr. Mag., **22**, 23-34, 97-112 (1917).
[3] W. F. G. Swann, Phys. Rev., **43**, 217-220 (1933).
[4] M. S. Vallarta, Rev. Modern Phys., **11**, 180-189 (1939).
[5] M. S. Vallarta, Rev. Modern Phys., **11**, 188-189 (1939).
[6] W. Grotrian, Naturwiss., **27**, 555-563, 569-577 (1939).
[7] Encyclopedia Britannica. **2**, 11th ed., 927-934 (1910).
[8] H. T. Stetson, Science, **90**, 482-484 (1939).
[9] H. H. Clayton, Terr. Mag., **45**,13-17 (1940).
[10] L. V. Berkner, H. W. Wells, and S. L. Seaton, Terr. Mag., **44**, 283-311 (especially 309) (1939).
[11] Terr. Mag., **36**, 255 (1931); **37**, 259-260 (1932); **38**, 301-302 (1933); **39**, 237-238 (1934); **40**, 383-384 (1935); **41**, 351-352 (1936); **42**, 395-396 (1937); **43**, 471-472 (1938); **44**, 391-393 (1939); **44**, 94-99, 215-219, 349-351, 487-491 (1939).

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
SUBURBAN LABORATORY,
Needham, Massachusetts

PADRE LUIS RODÉS, S.J., 1881-1939

By J. B. Macelwane, S.J.

In the death of Father Louis Rodés, June 7, 1939, at Biniaraix on the Island of Majorca, the Observatory of the Ebro lost its capable director and geophysicists throughout the world an esteemed colleague and friend.

Louis Rodés* was born at Santa Coloma de Farnés, Spain, December 31, 1881. At the age of sixteen he entered the Society of Jesus. After two years of novitiate at Gandia and seven years of brilliantly successful classical, scientific, and philosophical studies at Saragossa and Tortosa he matriculated in the Faculty of Science of the University of Barcelona. While at the University during the years 1906 1910 he filled with distinction the post of Professor of Physics in the Jesuit College of Sarriá.

For his theological studies he was sent first to Tortosa and then to Ignatius-Kolleg in Valkenburg, Holland, where he was ordained to the Catholic priesthood in the summer of 1913.

In 1914 he was sent as representative of the Observatory of the Ebro to Hernosand in Sweden to observe the solar eclipse of August 21 of that year. Two years later, in 1916, he came to the United States where he was to spend three years in the study of astronomy and astrophysics at Harvard, at Chicago, and at the Yerkes and Mount Wilson observatories. To this period belong his researches on the spectroscopic determination of the rotation of the inner planets and also some gravitational studies including the design of a differential gravity-meter not very different from the gravimeter constructed a dozen years later by Haalck.

Toward the end of 1919 he was appointed Director of the Ebro Observatory. From this forward for nearly twenty years his tireless energy was expended on the development of the Observatory and its complex and many-sided program of astrophysical, heliophysical, and geophysical observations, of all of which he was the soul and for much of which he was personally responsible.

His work on the various forms of solar activity, especially on sunspots and flocculi and their influence on the Earth's magnetic and electric fields is well known. So also is his index of solar activity. His method of measuring the solar parallax is remarkable for its simplicity and precision. He was active in nearly every field of geophysics—terrestrial magnetism, atmospheric and terrestrial electricity, meteorology, seismology, hydrology.

The *Boletin Mensuel* of the Ebro Observatory which he edited is only a partial record of his indefatigable scientific labors during the two decades of his directorship. His many-sided interests and activities are reflected in the list of his publications which is appended below—besides these he published very many popular articles. In addition, he was a member of many national and international scientific societies and a faithful collaborator on many international commissions. Almost up to the moment of his untimely death he struggled to maintain this international cooperation in spite of discouraging obstacles. The following are some of the organizations to which he belonged and in which he took an active interest: American Astronomical Society; American Association for the Advancement of Science; American Association of Variable

*The writer is indebted to Reverend Antonio Romañá, S.J., successor of Father Rodés as director of the Observatory of the Ebro, for most of the facts mentioned in this sketch, for the list of publications, and for the excellent photograph of Father Rodés reproduced in Plate I.

Star Observers; Astronomische Gesellschaft; Academia de Ciencias y Artes de Barcelona; Academia Colombiana de Ciencias Exactas fisicoquimicas y naturales; Academia Nacional de Ciencias "Antonio Alzate", Mexico; Academia das Ciencias do Portugal; Asociación Española para el Progreso de las Ciencias; Comité Nacional de Astronomia; Comité Nacional de Geodesia y Geofisica; Gesellschaft zur Foerderung der Geophysik in Bayern, Kuratorium; Instituto de Coimbra; Sociedad Astrónomica de España y America; Sociedade de Meteorologia e Geofísica, Coimbra (first foreign number); Società Sismologica Italiana; Société Astronomique de France; Société Météorologique de France; Societat Catalana de Ciencias Fisiques, Quimiques i Naturels.

Father Rodés was also an active member of many international scientific commissions as, for example, the following:

International Union of Geodesy and Geophysics—Commission pour méthodes et instruments pour l'observation de courants telluriques (1922); Commission pour le choix des emplacements de nouveaux observatoires et la répartition de leurs travaux en Europe (1930) (1933); Commission pour l'étude des orages magnétiques à début brusque (1933); Commission pour la charactérisation électrique des jours (1933) (1936); Commission for the polar year; International Commission of Snow.

Organisation Météorologique Internationale—Commission de magnétisme terrestre et électricité atmosphérique; Commission pour l'étude des nuages; Commission pour l'exploration de la haute atmosphère.

International Astronomical Union—Commission 11, Phénomènes chromosphériques; Commission 10, Taches Solaires et des Figures charactéristiques Solaires; Commission 12, Physique Solaire; Commission for the reform of the constitution of the Union.

Commission on the Reform of the Calendar—President of the Spanish Committee of the World Calendar Association and consultant of the international committee of the Association.

Many of the readers of this JOURNAL will remember the genial and friendly personality of Father Rodés at many of the international meetings at which he was very active. He will be greatly missed by his colleagues in many fields of geophysics.

Father Rodés suffered much physically and mentally during the first revolution when the Ebro Observatory was slated for confiscation and especially during the Spanish civil war when he was told that the lives of his subordinates depended on his behavior. During the last months of the civil war he was taken to Barcelona. By the time of the Nationalist victory his health was completely undermined. He was sent to Majorca for a complete rest; but died there June 7 at the comparatively early age of fifty-eight.

List of Publications of Father Rodés

Curiosidad Aritmética, Razón y Fé, Junio de 1906.
Estratificación de la Materia, Razón y Fé, Sep. 1910.
De los Cuerpos reales al éter hipotético, Razón y Fé, Mayo, Junio, Julio, Agosto, Sep., y Oct. 1911.
Eclipse de 21 de Agosto en Ernosand (Suecia), Ibérica, No. 37, Vol. II.
Registro fotográfico en ondas hertzianas, Ibérica, No. 38, Vol. II.
Viaje científico—Hacia el Eclipse, Ibérica, No. 41, Vol. II.
El Instituto de Física de Bona, Ibérica, Vol. II, Dic. 1914.

Un Fotómetro ideal: La célula de potasio y su aplicación en Astronomía. Ibérica, Vol. IV, Septiembre de 1915, y Vol. IV, Oct. 1915.

El "Weather Bureau" de los Estados Unidos y la cosecha nacional, Ibérica, Vol. VII, Junio 1917.

XXI Congreso Astronómico Norteamericano, Ibérica, Vol. VIII, Oct. 1917.

El Avance de Lyman en la región ultraviolada del espectro, Ibérica, Vol. VIII, Sep. 1917.

Organización Meteorológica en los Estados Unidos: Su desarrollo progresivo en orden a la navegación y a los intereses agrícolas, Nota presentada al Congreso de Sevilla de la Asociacíon Española para el Progreso de las Ciencias, en la sesión del 9 de Mayo de 1917, Madrid, E. Arias.

Prácticas del "Rowland" cóncavo, Ibérica, Vol. IX, Feb. 1918.

Una visita al Observatorio de Yerkes, Ibérica, Vol. X, Nov. 1918.

Direct application of Wulf's electrometer for recording the time sent by wireless telegraphy and its connection with the potassium photo-electric cell to register the duration of the totality in a solar eclipse, Amer. Astr. Soc., Vol. III, 1918.

El observatorio de "Harvard College", Archivo Celeste, Ibérica, Vol. X, Dic. 1918.

Harvard. Una gran Universidad libre norteamericana, Razón y Fé, 1918.

Una visita al Observatorio de Yerkes. Horizontes Astronómicos, Ibérica, Vol. X, Oct. 1918.

El Principio de Doppler-Fizeau en su relación con la Ley de Kirchhoff, Revista R. Acad. Ciencias Exactas, Físicas y Naturales, tomo XVII, Abril, Mayo, y Junio 1919.

A Discussion of the Spectroscopic Method of Determining the Rotation Periods of the Inner Planets, The Observatory, No. 542, Vol. XLII, Agosto 1919.

The Relation of the Doppler-Fizeau Effect to Kirchhoff's law. Pub. Astr. Soc., Pacific, No. 180, Vol. XXXI, Abril 1919.

On the Relative Intensity of the Absorption Lines in a Spectroscopic Binary, Pub. Astr. Soc., Pacific, No. 180, Vol. XXXI, Abril 1919.

Discusión teórica sobre los medios para determinar espectroscópicamente la rotación de los planetas interiores, Revista Soc. Astr. España y América, No. 66, Mayo-Junio 1919.

Magnetic Storm of March 22, 1920, as recorded at del Ebro Observatory, Terr. Mag., Junio 1920.

A Differential Gravimeter and its applications, Pub. Astr. Soc. Pacific. No. 185, Febrero 1920.

Harmonies del Firmament, Conferencia Astronómica, 64 páginas con 22 figuras, Barcelona, Oliva de Vilanova, 1920.

Instituciones Científicas de los Estados Unidos. 1 foll. en 4° de 124 páginas con 44 figuras.

Inventario de los Cielos, La Zuia, No. 89, Nov. 1920.

Monte Wilson, Una gran Atalaya de Observación Cósmica, Ibérica, Vol. XIII, 13 y 27 de Marzo 1920.

Bibliografía de "Die Veränderlichen Sterne", Ibérica, Vol. XIV, Agosto 1920.

Los Eclipses de Estrellas por Planetas, Revista Soc. Astr. España y América, No. 71, 1920.

Bases generales para un proyecto de organización meteorológica, Boletín Soc. Astr. Barcelona, Vol. IV, números 29-34, Abril-Junio 1920.

Is the Problem of the Rotation of the Inner Planets Settled? The Observatory, No. 565, Vol. XLIV, Junio 1921.

La actividad solar durante el último ciclo y estudio de la influencia de la Tierra en la formación de las manchas, Conferencia, Congreso de Oporto de la Asociación Española para el Progreso de las Ciencias, 1921, Tomo II, Madrid, Gimenez Molina.

La Tempête Magnétique de mai 1921 à l'Observatoire de l'Ebre, Ciel et Terre, Julio, Agosto 1921.

La Terre exerce-t-elle une influence sur la formation de taches du soleil? C.-R., 3 Octubre, 1921.

A Probable Influence of the Earth on the Formation of Sun-spots, Pop. Astr., Enero, 1922.

El Excmo. Sr. D. José J. Lánderer, Un sabio eminente y un católico modelo, Boletín Oficial Eclesiástico de la Diócesis de Tortosa, Septiembre 1922.

Necrología del Sr. Lánderer, La Estrella del Mar, No. 67.

Note sur l'éclipse de Soleil du 28 Mars 1922, Ciel et Terre, 1922.

On the non-simultaneity of magnetic storms, Terr. Mag., Diciembre 1922.

La Espectroscopía, Llave de la Astronomía Moderna, Memorias R. Acad. Ciencias y Artes, Vol. XVIII, No. 1.
La pérdida de un gran astrónómo, Edward Emerson Barnard, Revista Soc. Astr. España y América, No. 89, Mayo-Junio 1923.
Una Estrella, La Estrella del Mar, No. 104, 12 Agosto 1923.
La Astronomía Impulsora del arte Fotográfico, El Progreso Fotográfico, No. 43, Enero de 1924.
The Effect of Cosmic Clouds on the Period of Variable Stars. Pop. Astr., Marzo de 1924.
The Effect of the Sun on the Magnets, Pop. Astr., Enero 1924.
El Firmamento, Nuestra Revista, Buenos Aires. No. 68, Mayo 1924.
Las Nubes cósmicas y las irregularidades en el período de ciertas estrellas variables, Memorias R. Acad. Ciencias y Artes, Vol. XVIII, No. 10, Mayo 1925.
Los cambios de nivel en las cuevas del Drach (Manacor, Mallorca) y su oscilación rítmica de 40 minutos, Ibérica, No. 573, 11 Abril 1925.
Los cambios de Nivel en las cuevas del Drach (Manacor, Mallorca) y su oscilación rítmica de 40 minutos. Memorias R. Acad. Ciencias y Artes, Vol. XIX, No. 7, Julio 1925.
Zweiter Kongress der "Internationalen Astronomischen Union" von Cambridge, 14-22 Juli 1925, Schweizerische Rundschau, Septiembre 1925.
El Curso de las estrellas, Razón y Fé, No. 305, 15 de Julio 1926.
Las manchas solares, La Ilustración, No. 1, 1 de Diciembre 1926.
Some New Remarks on the Cause and Propagation of Magnetic Storms, Terr. Mag., Septiember-Diciembre 1927.
El Firmamento, 586 pág. con 348 fig., Barcelona, Salvat Editores, S.A. 1927.
Excursión a través de los Observatorios norteamericanos, Conferencia (extracto) Boletín Un. Nacional de la Plata, Tomo XI, Diciembre 1927.
Harvard, Una Gran Universidad Libre Norteamericana, San Ignacio, Revista mensual No. 14, Noviembre 1927.
Sur nune ouvelle méthode pour mesurer la parallaxe solaire. C-R., 24 Septiembre 1928.
A New Independent Method for Measuring the Solar Parallax. Vierteljharsschrift der Astr. Gesellschaft, Viertes Heft, 1928.
Un nou metode independent per mesurer les dimensions i distancia al Sol. Ciencia, No. 25, Novembre 1928.
Intercambio Hispano Americano 1 foll. de 80 pág. Barcelona, Salvat Editores, S.A.
Un Nuevo método independiente para medir la dimensión y distancia al Sol Memorias R. Acad. Ciencias y Artes de Barcelona. Vol. XXI, No. 11, Diciembre 1928.
Un Nuevo Indice de Actividad Solar, Congreso de Barcelona de la Asociación Española para el Progreso de las Ciencias, 22 de Mayo de 1929, Madrid, Huelvos y Compaña.
Una nueva determinación de la distancia Solar, 1 foll. en 8° de 27 pág., Tortosa, Algueró y Baiges, 1929.
Los Soles vecinos al nuestro, La Zuia, No. 183, Septiembre 1929.
XXV Aniversario de la Fundación del Observatorio del Ebro. 1 foll. en 8° de 15 pág.
Sesión Necrológica en homenaje al R. P. Federico Faura, S. J., Memorias R. Acad. Ciencias y Artes de Barcelona, Vol. XXII, No. 5, Julio 1930.
The Periodic Variation of Atmospheric Potential Gradient, U. G. et G. I., C.-R. l'Assemblée de Stockholm, 1931.
Période diurne et annuelle dans la distribution de 1944 tremblements de Terre enregistrés par un même sismographe, C.R., tome 190, 1930.
Id. id, Gerlands Beiträge zur Geophysik, tome 28, 1930.
Instalación de Estrellas en la cúpula del Pabellón Lánderer del Observatorio del Ebro, Ibérica, Vol. 38, 9 de Julio 1932.
Período diurno annal y secundario en las perturbaciones súbitas del campo magnético terrestre, Terr. Mag., Vol. 37, Septiembre 1932.
Reverendo Ricardo Cirera, S.J., Terr. Mag., Diciembre 1932.
Periode diurne et annuelle dans la distribution de 1944 tremblements de Terre enregistrés par un même sismographe, U.G. et G. I., Section de Séismologie, Conférence de Stockholm, Agosto de 1930.
Una audición de la "Missa Solemnis", Revista Musical Catalana, No. 348, Diciembre 1932.
Las perturbaciones magnéticas, Blanco y Negro. No. 2180, Marzo 1933.
Puede predecirse el tiempo mirando el Sol? A Terra, Coimbra, No. 7, Enero 1933.
Acción del Sol en el gradiente del potencial eléctrico de la atmósfera y en las perturbaciones súbitas del campo magnético terrestre, Memorias R. Acad. de Ciencias y Artes de Barcelona, Vol. XXXIII, No. 11, Julio 1933.

The Influence of the Moon on the Frequency of Earthquakes, U. G. et G. I., Association de Séismologie, reunión de Lisboa, Septiembre 1933.
Lluvia de Estrellas, Juventus, Barcelona 15 de Noviembre de 1933.
Insinuaciones, Crónica de la Expedición Iglesias al Amazonas, Agosto 1933.
Un Siglo de Progreso en la medición de distancias celestes, 1 foll. en 8° de 26 pág.
Acción del Sol en los imanes, Investigación y Progreso, Madrid, 1° de Marzo 1934, Año VIII.
Étude de la parallaxe solaire, Note de L. Dufons, Ciel et Terre, Juin-Juillet, 1934.
The Influence of the Moon on the Frequency of Earthquakes, Gerlands Beitr. Geophysik, Vol. 41, 1934.
Enregistrement et mesure des flocculi, Draft Report 1935, 11 Commission des Phénomènes Chromosphériques.
Del Ebro, Draft Report 1931, 10 Commission des taches solaires et des nombres caractéristiques solaires.
Volando de Estrella a Estrella, Mundo Católico, No. 1, 1° de Junio 1935.
Resumen 1910-1934, fasc. 1 Heliofísica, 18 págs. con 3 figuras, Tortosa, Imprenta Moderna de Algueró y Baiges, 1936.
El Firmamento, edición reducida, 1 en 8° de 247 pág. con 133 fig., Barcelona, Salvat Editores, S. A. 1934.
Resumen 1910-1934, fasc. 2° Meteorología, Contribución al estudio Climatológico de la commerca de Tortosa y Atlas de Nubes., 1 en 4° de 65 pág. con 15 fig. y 45 láminas, Tortosa, Imprenta Moderna de Algueró y Baiges, 1936.
Influye la Luna en el Tiempo? Memorias del Observatorio del Ebro, No. 7, 1 en 4°, de 35+LXXII pág. con 12 fig., Tortosa, Imprenta Moderna de Algueró y Baiges, 1937.
Report to the President of the Committee on Sudden Commencements, Pág. 177, 178 y 179 de Transactions of the Edinburgh Meeting, Sept. 17-24, 1936.
Darstellung des Windes über Tortosa, Secretariat de l'Org. Met. Ins. No. 27, Leyden, 1936.
La Aurora boreal del 25 de Enero, Urania, Rev. Soc. Astr España y América, No. 202, Marzo 1938.
La réalité de l'influence de la Lune sur le temps, La Météorologie, Sept.-Oct. 1938, pp. 297-309.
Grêlons de dimension exceptionelle, La Météorologie, ibid., pp. 320-321.

St. Louis University,
St. Louis, Missouri

NOTES

(See also page 112)

1. *United States Antarctic Expedition* An expedition, prepared by the United States Antarctic Service, sailed in December 1939 for Little America, under the leadership of Rear Admiral Richard E. Byrd. It is planned, during a sojourn of two or three years in the antarctic, to carry out a wide scientific program including seismological, auroral, geomagnetic, radiotelegraphic, and cosmic-ray observations. A magnetic observatory will be established either at Little America, site of Admiral Byrd's headquarters on his last expedition or within the belt of maximum auroral frequency, depending on conditions encountered. The program also includes magnetic observations at various points on the continent which will be reached by the snow-cruiser, a new feature of the Expedition. Roy G. Fitzsimmons who has had previous experience in arctic work will have charge of the magnetic and seismological observations, assisted by M. A. Wiener. The instrumental equipment for the magnetic work was furnished partly by the United States Coast and Geodetic Survey and partly by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. That Institution's

Committee on Coordination of Cosmic-Ray Investigations lent the Expedition for installation in Little America two Millikan-Neher type meters for obtaining during the winter continuous records which will be eventually studied for fluctuations and correlation of the intensity with values obtained at other stations. The meters will be operated on the ship while en route to Little America chiefly to determine whether the latitude-effect ceases south of New Zealand and whether correlations with external temperature can be established. One of the meters will be carried to various heights by airplane to obtain the variation in intensity with altitude in this region for comparison with data from northern flights. A Geiger-counter apparatus is also being taken which is of an experimental nature for measuring the total cosmic-ray intensity. Mr. E. T. Clarke accompanied the supply-ship *North Star* to install the meters and instruct the observers in their operation.

2. *Guatemalan Volcanological Expedition of 1940* The general cooperative project of geophysical investigation of the region of marked volcanic activity in Guatemala inaugurated in 1939 (see Terr. Mag., **44**, p. 20, 1939) by the Geophysical Laboratory and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington is being continued during the dry season of 1940, under the direction of Dr. E. G. Zies. W. J. Rooney of the Department of Terrestrial Magnetism, accompanied by J. W. Green, retired staff-member, proceeded to Guatemala in December. An attempt will be made to determine the structural details of one or more characteristic valleys of the region by earth-resistivity measurements. It is further proposed to supplement the resistivity-survey by additional magnetic measurements.

3. *Geophysical work at Ógyalla*—In accordance with the Italo-German mediation of November 2, 1938, certain Czechoslovakian territory including the Observatory of Ógyalla was restored to Hungary. This observatory was founded in 1900 and was operated from 1918 to 1938 under the name of Stará Dala. The Royal Hungarian Institute for Meteorology and Terrestrial Magnetism has taken charge of the reorganization of the observatory, installing the necessary instruments for a general program of geophysical work. It is proposed to publish the results in monthly bulletins of which the first four (January to April 1939) have been received. In addition to the results of meteorological observations, they contain those of potential-gradient and the departures of the hourly means of westerly magnetic declination from the monthly means.

4. *New magnetic observatory in South Africa* Referring to our note on page 394 of the December 1939 number of this Journal, we are now informed that work on the building of the magnetic observatory at Westcliffe, Hermanus, will be started immediately, the period given for the contract being five months.

5. *Corrigenda*—In the December 1939 number of this Journal the second paragraph under *Personalia* should read "Dr. Otto Schneider" instead of "Dr. Otto Schnider." The twenty-second line on page 477 of the same number should read "magnetic" instead of "map-making."

REVIEWS AND ABSTRACTS

T. A. Wormell: *The effects of thunderstorms and lightning discharges on the Earth's electric field.* Phil. Trans. R. Soc., A, **238,** 249-303 with 19 figs. and 16 pls. (1939).

Observations taken near the Solar Physics Observatory, Cambridge, England, chiefly in summer in the eleven years 1926-36 are the basis for this paper. The instruments used in the observations were the "test-plate" and "elevated sphere" devised by C. T. R. Wilson, with slight modifications, connected to a capillary electrometer of the type used by Wilson. The sphere could be placed at heights of 4.8 and 1.5 meters, the former height being suitable for observations on the more distant and smaller field-changes. Two test-plates were used, one at ground-level, the other inverted and mounted on an arm extending horizontally from a post 1.5 meters high. Any one of these collector-systems could be connected, as desired, to the electrometer to provide suitable sensitivity of the apparatus for different conditions. In this way, field-changes ranging from a few volts per meter to 50,000 or 60,000 volts per meter could be measured and, with the electrometer adapted for photographic recording, continuous records could be made of the field during thunderstorms and of the field-changes accompanying lightning-flashes. The sixteen plates accompanying the paper are reproductions of some of the more interesting field-changes recorded, and many are discussed in detail.

About 6000 field-changes appear to have been available to the author as material for his tables, curves, and analyses, and for about half of the number the distance away was satisfactorily determined. Field-changes are designated as positive when they are such as to increase a positive potential-gradient or decrease a negative. "Simple" field-changes involve only changes of one sign, although several component-changes may enter into each such field-change. "Complex" field-changes involve component-changes of both signs. Simple and complex field-changes are separated out as far as possible in the analysis, though the distinction between the two types was admittedly not always clear cut.

Before taking up the field-changes, the potential-gradient prevailing just before a lightning-flash, called the predischarge potential-gradient, is discussed in some detail. The records showed that it might have any value from zero to 10,000 volts per meter; only on very rare occasions did it exceed the latter figure. The sign might be either positive or negative whatever the distance to the storm-center but, on the whole, for storms nearer than ten km there was a preponderance of negative gradients and for storms beyond ten km a preponderance of positive. From a study of duration and magnitude of positive as compared with duration and magnitude of negative predischarge gradients, for different distances, it was found that, *on the average*, the potential-gradient is negative for all distances up to about 15 km, and is positive at greater distances. At 20 km it is only of the same order as the fair-weather gradient. It is then shown that a negative charge in the lower part of the cloud, at about three-km height, and a positive upper charge best fit these results. The very small average value of the field for a distant storm suggests that usually the lower negative charge considerably exceeds in magnitude the upper positive charge.

Discussing next the field-changes accompanying lightning-flashes, the effects of various kinds of flashes on the field at the observation-station are first reviewed. A flash carrying a charge of one sign to Earth (or to the conducting upper atmosphere if, as the author remarks, such flashes occur) causes at the observing-station, at any distance, a field-change of sign opposite to the sign of the charge transported. A vertical flash that does not reach the Earth causes no field-change at some particular distance from the flash, but inside and outside of that distance (the reversal distance) the field-changes are opposite in sign. Flashes inclined to the vertical complicate the interpretation, for the reversal distance is greater or less than for vertical flashes, depending on whether the inclination is away from or toward the observer. Analysis of the field-change data showed that, on the average, the magnitude of the field-change, regardless of sign, was less the greater the distance to the discharge. Simple and complex field-

changes were alike in this respect. At two or three km the magnitude rarely exceeded 20,000 volts per meter, at four or five km 10,000, at ten km 3000, at 15 km 1000 to 2000, and at 25 km was always less than 1000 volts per meter. Positive field-changes were more numerous than negative, and the results are in accord with those of other investigators in that positive field-changes were in considerable preponderance for fairly close storms, while negative field-changes were found more and more frequently as the storms observed were more distant and the field-changes smaller. This was interpreted as indicating the frequent occurrence of a type of lightning-flash not reaching the ground but which, in effect, raises the height of a negative charge, or lowers a positive. For flashes in very close storms (less that three km away) the new fact was disclosed that the proportion of negative field-change was very much greater than for flashes at slightly greater distances, and the author suggests as explanation the occurrence of a type of lightning-flash not reaching the ground but which, in effect, lowers a negative or raises a positive charge. Such discharges would need to be low, their centers usually not more than two km from the ground, and they could not be of great vertical length.

The most frequent value of the electric moment of a positive discharge was about 130 coulomb-km and that for a negative about 110 coulomb-km. The mean value, however, for either sign was much higher, 220 coulomb-km, owing to occasional discharges of very high moment. It was calculated that the quantity discharged in the great majority of lightning-flashes lay between 10 and 40 coulombs, the corresponding heights of the centers of discharge being about ten and three km, respectively. The average quantity was close to 20 coulombs with the center of discharge at about five km.

The character of complex field-changes and their electrical effects are discussed in the next section of the paper, and this is followed by consideration of the duration of field-change. The records showed that, while many field-changes exhibited no appreciable duration, it was quite common for a simple field-change of either sign to last more than 0.1 sec and a few exceeded 0.5 sec. The components of complex field-changes had durations of the same order.

With regard to the frequency of lightning-discharges at the station, it was concluded that the correct figure would be about one flash per square km per year. As only a fraction of the discharges observed were flashes to Earth, and as they included discharges of both signs, it was definitely concluded that the electric charge brought to Earth by lightning in the vicinity of the station is much smaller than the integrated air-earth current of fine weather, and probably much smaller than the transfer of electricity by point-discharge currents.

The observations seemed to establish definitely that the recovery of the field after a lightning-discharge, except in cases when the field-change created a very intense field, was on the average much slower after discharges within ten km than after those more distant. It was also definitely shown that the initial rate of regeneration of electric moment in the cloud was, on the average, at least 15 per cent per sec of the moment destroyed by the discharge.

In the final section, under remarks, the author discusses various aspects of thundercloud structure. Taking from the observations average values of the electric moment of a discharge and of its initial rate of recovery, and assuming values for the critical field to produce discharge, and for the velocity of fall through the cloud of the larger carriers, he finds that the weight of water in the cloud would exceed 1.4×10^{11} grams, the charge would be about 1400 coulombs, and the volume of the cloud about six cubic km. He then remarks that the regular occurrence of a region of positive charge in the base of a cloud as suggested by Simpson and Scrase in 1937 cannot be said to be definitely established, and various alternative suggestions based on the present results are made. In the last few paragraphs it is pointed out that whether the carriers of charge in the cloud be water-droplets or ice-crystals, Wilson's theory for the mechanism of thundercloud formation remains a satisfactory one.

The great number of observations utilized in the paper gives weight to the suggestions offered and the conclusions drawn by the author. Many of the suggestions and conclusions have been stated in this review, at a sacrifice of brevity, because they seemed of particular interest. While the results have supported, throughout, the idea that storm-clouds are bipolar, and mainly positively polarized, the importance of this arrangement in the replenishment of the Earth's charge in accordance with Wilson's theory is not directly discussed by the author. The discussion in the paper is well systematized and the division into sections aids greatly in the presentation of the material. The paper can well be called an important contribution to the literature on thunderstorms and atmospheric electricity.

O. W. Torreson

B. N. Lahiri and A. T. Price: *Electromagnetic induction in non-uniform conductors, and the determination of the conductivity of the Earth from terrestrial magnetic variations.* Phil. Trans. R. Soc., A, **237**, 509-540 (1939).

This valuable paper concerns the induction of electric currents within a non-uniform conductor in the presence of a varying electromagnetic field. Calculations are made of possible distributions of electrical conductivity compatible with the geomagnetic solar daily and storm-time variations, for the region extending from the surface of the Earth to a depth of about 1000 km, thus presenting new tentative information respecting the nature of the Earth's interior.

The writers first mention the early work of Schuster who suggested that certain geomagnetic variations were caused by varying external electric currents together with their induced currents within the Earth. Schuster also considered the internal conductivity of the Earth consistent with the solar daily variation. Using more complete data Chapman later showed that the solar daily variation was compatible with an Earth having a core of conductivity $\kappa=3.6\times10^{-13}$ electromagnetic unit surrounded by a non-conducting shell about 250 km thick. Chapman and Whitehead later considered the effects of the relatively highly conducting oceans and of the Earth's magnetic permeability in modifying this estimate of κ. Using the theory of Price for aperiodic fields in the presence of a uniformly conducting sphere Chapman and Price later inferred that κ increased with increasing depth to values greater than 10^{-13} electromagnetic unit beyond 250 km. In the present paper this increase in κ and the effects of the conducting oceans are examined by developing and applying the theory of induction of electric currents for a non-uniform sphere.

The general electromagnetic theory of the induction of currents in any non-uniform conductor is first presented. A differential equation involving the vector potential and the potential of the instantaneous charge-distribution within the conductor is obtained. It is shown that the displacement-current is small compared with the conduction-current in the case of a conductor having the linear dimensions and probable physical properties of the Earth, when the period of the inducing current is greater than about one second. Next considered is the special case in which the dielectric constant and magnetic permeability of the conductor are constant, while the conductivity is a variable function of position within the conductor; the equations and boundary-conditions are given for the case when the conductor is surrounded by a dielectric. These equations show that there is ordinarily a minute surface-electrostatic charge (but no volume-charge for certain distributions of κ) deflecting any induced currents approaching the surface of the conductor so that they flow parallel to this surface. The equations are next solved formally for the case when κ varies only with the distance r from the center of a sphere of radius a, so that $\kappa=\kappa(\rho)$ where $\rho=r/a$, the function $\kappa(\rho)$ being a differentiable function of ρ. Heaviside operational methods are indicated for expressing the solutions found in terms of the observed surface magnetic field of the sphere for the cases where the inducing field is periodic and aperiodic in time. The authors next give detailed solutions for the induced field and the internal current-distribution for the case when the permeability $\mu=1$, $\kappa=k\rho^{-m}$, where k is a constant and m a positive integer. Numerous supplementary and asymptotic formulas are derived permitting the calculation of the field and current in practice for large and small values of m.

The results for the case $\mu=1$, $\kappa=k\rho^{-m}$, where $\rho=r/qa$ (for $q<1$), are next applied to the solar daily variation. It is first supposed that there is a non-conducting layer overlying a conducting core of radius qa of the Earth. It is concluded that the values (m, k, q) of $\kappa=k\rho^{-m}$ consistent with the spherical harmonic constituent P^2_3 of the solar daily variation will range between $(0, 3.6\times10^{-13}, 0.96)$ to $(30, 4\times10^{-14}, 1)$. Other harmonic constituents of this variation are not considered because they probably are not yet known to the required degree of accuracy.

The same considerations applied to the field of the storm-time variation showed best agreement with the distribution $\kappa=k\rho^{-m}$ for values of m near 30, the upper limit found for the solar daily variation. The authors hence conclude that the form of the actual distribution of conductivity probably differs in some respect from the (m, k, q)-model. They therefore introduce a correction in the distribution partly accounting for the highly conducting oceanic areas of the Earth. They point out that the agreement of the results for the two geomagnetic variations would improve if the permissible conductivity of the inner core could be increased by screening it more effectively by surrounding conducting layers, in the case of the periodic solar daily variation. It is calculated that the thickness of ocean required must be between about one-quarter and one-half mile for an idealized ocean extending over the entire Earth. With thickness about one-quarter mile it is found that $m=37$, $k=4\times10^{-14}$ electromagnetic unit, and

$q=1$ will give the correct internal fields for both the daily and storm-time variations. For this distribution of κ they estimate that below the idealized ocean and "down to depths of 200 or 300 km and possibly as far as 600 km," κ will not be much greater than about 10^{-15} electromagnetic unit, the measured conductivity of surface-rocks. The conductivity begins to rise very rapidly at a distance of about 0.1 a (600 or 700 km) from the surface. The conductivity below this depth must be at least as high as 10^{-11} electromagnetic unit and may continue to rise to much higher values. The geomagnetic variations considered do not afford information as to the conductivity for depths beyond about 0.2 a.

In the case of a steady daily variation nearly all of the induced currents flow between depths from about 600 to 1000 km, the computed current-density being nearly zero at a depth of 1200 km. For the storm-time variation rough indications suggest that during the initial increase in H, a pulse of westward induced currents rapidly penetrates inwards from the Earth's surface reaching a depth of 200 km in about five minutes. The maximum current-density at first decreases as it penetrates inwards, but after a depth of about 900 km is reached (in about six hours) it begins to increase again as $1/\rho$. The speed at which the point of maximum current-density progresses inwards now decreases rapidly, proportionally to ρ^{36}. The total induced current continually diminishes, so that the variation of current-density with depth shows a maximum of increasing sharpness with increasing depth. A depth of about 1200 km is reached in about 48 hours. With the transition from the initial to the main phase of the storm the initial pulse is followed in about four hours by a much greater pulse of eastward current, following the westward one inwards and gradually overtaking it. The subsequent slow recovery of the external field then produces a less intensive but more extended pulse of westward current, which gradually overtakes and cancels the previous pulse.

The rapid increase in κ at a depth of about 700 km suggests some change in the composition of the Earth near this level. This is also suggested by certain evidence of seismology, which has been interpreted to indicate a sharp increase in density at a depth of several hundred km. There is also some evidence of a change in elastic properties at an estimated depth of about 500 km.

The magnetic data used in the paper are less accurate than other data now available. The writers warn that the results obtained should not be pushed too far and are using better data in making improved calculations. Although the limits of the accuracy of the data have sometimes been subjected to considerable strain, it appears probable that the general indications of this study should be fairly closely supported by more accurate data. In future discussions it would also appear desirable to use an idealized ocean conforming more nearly to the actual distribution of oceanic areas of the Earth. It is to be hoped also that estimates of κ at depths greater than 0.2 a may be forthcoming from data on non-cyclic change, and from the annual changes in geomagnetism. The theory of the paper could also perhaps be profitably applied to the numerous periodic and aperiodic changes lasting only a few hours, in inferring the conductivity of the Earth s crust.

A few misprints have been noted in the mathematical formulas; an obvious one occurs in the fundamental formula (4, 1) and a minor inconsistency in the definition of $\mathbf{A}_1$.

E. H. Vestine

LETTERS TO EDITOR

(See also page 18)

THE FOURTH CENTENARY OF WILLIAM GILBERT OF COLCHESTER

In view of the important contribution to the science of terrestrial magnetism made by William Gilbert, it seems fitting to recall that 1940 marks the fourth centenary of his birth. We are indebted to the article by E. C. Smith, *Nature* of January 6, 1940, for some of the facts given below.

He was born at Colchester, County Essex, England, in 1540. Little is known with certainty of his early days but at the age of twenty he graduated from St. John's College, Cambridge. He later spent several years in travel and study on the Continent and in 1569 obtained the degree of M.D. Four years later he settled in London to practice medicine, becoming ultimately physician to Queen Elizabeth. In due time he rose to be President of the Royal College of Physicians and to it he bequeathed his books, globes, and apparatus, which unfortunately were all destroyed in the great fire of London in 1666. Although he was thus a physician of no mean standing, the work which won him immortality had little to do with medicine, in which field, moreover, no important discovery is attributed to him. He died at Colchester, November 30, 1603, and was buried in Holy Trinity Church where a monument was erected by his brothers.

In 1600, at the age of 60, he published the epoch-making book "De Magnete, magnetisque corporibus et de magno magnete tellure," the first great work on physical science published in England. In this Latin treatise on the magnet he not only collected all the knowledge which others possessed on the subject but became at once the father of experimental philosophy in England. The work created a profound impression especially in other parts of Europe. It was by reading this book that Galileo, who expressed the highest admiration for its author, was induced to turn his mind to magnetism.

Gilbert's contribution to physical science and to the philosophical advancement of mankind was summed up as follows by Park Benjamin: "He was the first: To investigate natural phenomena philosophically and systematically, and by a true inductive method, for he interrogated nature by actual experiment and from the particulars thus ascertained rose to correct generalizations; to recognize electricity (as distinguished from magnetism) as a new natural condition or force, and to study and name it; to extract the facts and laws of magnetism from the existing mass of speculation, mysteries, and delusions, and reduce them to a science; to suggest the correlation of gravity and magnetism with other natural forces, and a relationship between gravity, magnetism, and electricity; to formulate a definite conception of the magnetic field of force, and to attempt to show its extent . . .; to recognize that the Earth is a great magnet, capable of magnetizing iron and iron ore by induction; to determine the magnetic polarity of the Earth, and in the directive tendency thereof to reveal the true reason for the verticity of the compass-needle; to discover magnetic screening, conduction, and saturation, the compound magnet, the mutual attraction or induction of lodestone and iron, the pole-piece or armature, the effect of induction on soft iron. . . . He invented the first electrical (as distinguished from magnetic)

instrument, the first electrical indicating device, the first magnetometer, filar suspension, and the ordinary method of magnetization."

Aside from his great contributions to physical science, he was also the first advocate of Copernican views in England, and he concluded that the fixed stars are not all at the same distance from the Earth.

Department of Terrestrial Magnetism, H. D. Harradon.
Carnegie Institution of Washington,
Washington, D. C., February 15, 1940

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS AT WASHINGTON, D. C., OCTOBER TO DECEMBER, 1939[1]

The following ionosphere data are in continuation of those published in this Journal[2] and in each issue subsequently. All critical frequencies are now given in terms of the ordinary wave; this involves no difference for the E- or F_1-layers but the F_2-layer critical frequency is about 750 kc lower than that for the extraordinary wave which was formerly given. *Errata*: The F_2-layer critical frequencies for July, August, and September [Terr. Mag., **44**, 483 (1939), were erroneously designated as $f^x{}_{F_2}$ and should have been designated $f^\circ{}_{F_2}$.

Key to symbols.

EST = Eastern Standard Time (75° west meridian time).

= manual measurements made on Wednesdays.

Other data were usually obtained daily.

Table 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.* (Average for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	$f^\circ{}_E$	$f^\circ{}_{F_1}$	$f^\circ{}_{F_2}$	h_E	h_{F_1}	h_{F_2}	$f^\circ{}_E$	$f^\circ{}_{F_1}$	$f^\circ{}_{F_2}$
h	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*
			October, 1939[a]						*November, 1939*[a]			
00			312			5460			298			4560
01			308			5300			289			4500
02			309			4970			290			4470
03			311			4690			285			4400
04			316			4300			274			4240
05			309			4020			282			3980
06	112#		293	1150#		4540	112#		297	920#		3870
07	113#	240	250	2250		7140	110#		233	1810		6130
08	119	235	270	2830		9060	112#		231	2470		8440
09	118	225	270	3200		10150	118#	225	235	2870		9780
10	117	222	282	3440		10880	122#	221	238	3130		10740
11	114	225	283	3570		11380	115#	219	248	3280		10800
12	116	225	279	3610		11770	113#	218	251	3330		11420
13	118	229	283	3590		11780	111#	225	251	3290		11620
14	119	231	286	3460		11750	113#	229	248	3130		11620
15	120	234	282	3200		11590	117#	232	242	2790		11480
16	118	237	265	2730		11180	116#		230	2270		10960
17	110#	240	250	2170		10530	107#		221	1430#		9670
18			236	1390#		9260			232			8170
19			252			8200			238			7250
20			252			7430			250			6090
21			277			6300			268			5290
22			307			6000			275			4970
23			300			5730			281			4720

[a] $f^\circ{}_{F_1}$ not well defined during October and November.

[1] Communicated by the Director of the National Bureau of Standards of the United States Department of Commerce.

[2] T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*—Continued

(Averages for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$
h	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*
			December, 1939[a]			
00			305			3760
01			316			3740
02			313			3820
03			305			3880
04			303			3860
05			303			3750
06	110#		295	800#		3690
07	112#		265	1090#		4650
08	122#		224	2130		7170
09	125#	224	233	2660		8380
10	121#	222	246	2950		9380
11	125#	221	243	3110		10140
12	121#	219	249	3170		10290
13	122#	222	253	3110		10370
14	117#	225	250	2940		10360
15	124#	230	235	2670		10210
16	118#		225	2270		9580
17	115#		225	1250#		8420
18			235	930#		7460
19			237			6320
20			240			4980
21			282			4280
22			289			4030
23			293			4000

[a] $f^\circ_{F_1}$ not well defined during December.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, OCTOBER TO DECEMBER, 1939, AND SUMMARY OF C_A FOR YEAR 1939

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The three columns for each month in Table 1 give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); 37, 85-89, 189-192, 409-411, and 484-487 (1932); 38, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937); **43**, 83-87, 174-178, 328-331, 491-494 (1938); **44**, 94-99, 215-219 349-352, 487-491 (1939).

TABLE 1—*Summary American URSI daily broadcasts of cosmic data, October to December, 1939*

Greenwich date	October Magnetism Character	October Magnetism Type	October GMT beginning disturbance h	m	November Magnetism Character	November Magnetism Type	November GMT beginning disturbance h	m	December Magnetism Character	December Magnetism Type	December GMT beginning disturbance h	m
1	0	...	..	..	0	...	..	..	0	*b*	05	52
2	0	...	..	..	0	...	..	..	0	...	..	..
3	1	*i*	08	00	0	...	..	..	0	...	..	..
4	1	*i*	..	..	0	...	..	..	0	...	..	..
5	0	...	..	..	0	...	..	..	0	...	..	..
6	1	*i*	05	13	0	...	..	..	1	*i*	20	08
7	0	...	..	..	0	...	..	..	1	*i*	..	..
8	0	...	..	..	0	...	..	..	1	*i*	..	..
9	0	...	..	..	0	...	..	..	0	...	..	..
10	0	...	..	..	0	...	..	..	0	...	..	..
11	0	...	..	..	0	...	..	..	0	...	..	..
12	0	...	..	..	0	...	..	..	0	*b*	02	30
13	1	*i*	02	05	1	*i*	01	46	0	...	..	..
14	2	*i*	..	..	1	*p*	..	..	0	...	..	..
15	2	*i*	..	..	0	...	..	..	0	...	..	..
16	1	*i*	00	00	0	...	..	..	1	*o*	22	35
17	1	*i*	..	..	0	...	..	..	0	...	..	..
18	0	...	..	..	0	...	..	..	0	...	..	..
19	1	*i*	04	00	0	...	..	..	0	...	..	..
20	0	...	..	..	0	...	..	..	0	...	..	..
21	0	...	..	..	0	...	..	..	1	*p*	05	45
22	0	...	..	..	0	...	..	..	1	*p*	..	..
23	0	...	..	..	0	...	..	..	0	...	..	..
24	0	...	..	..	0	...	..	..	0	...	..	..
25	0	...	..	..	1	*i*	02	00	0	...	..	..
26	0	...	..	..	1	*i*	..	..	0	...	..	..
27	0	...	..	..	0	...	..	..	1	*i*	..	..
28	0	...	..	..	0	...	..	..	0	...	..	..
29	0	...	..	..	0	...	..	..	0	...	..	..
30	0	...	..	..	0	...	..	..	0	...	..	..
31	0	...	..	..					0	...	..	..
Mean	0.4	...	..	..	0.1	...	..	..	0.2	...	..	

Greenwich mean time for ending of storms: $08^h\,30^m$, October 4; 10^h, October 6; 08^h, October 15 22^h, October 17; 11^h, October 19; 22^h, November 13; 11^h, November 26: 9^h, December 8; 24^h, December 16 20^h, December 22.

Beginning with October 27, 1938, Mount Wilson discontinued supplying sunspot-numbers, since interested investigators have available the sunspot-counts from Tokyo published regularly in the weekly Science Service Research Aid Announcements and the monthly tabulation of Wolf numbers, promptly prepared at Zürich, which appear monthly in the Monthly Weather Review and quarterly in this JOURNAL.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937,

TABLE 2—*Kennelly-Heaviside heights, Washington, D. C., October to December, 1939*
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1939	*kc/sec*	*km*	*1939*	*kc/sec*	*km*	*1939*	*kc/sec*	*km*	*1939*	*kc/sec*	*km*
Oct. 4	2,500	120	Oct. 25	5,400	240	Nov. 15	3,900	220	Dec. 6	3,500	230
" "	3,400	120	" "	8,600	280	" "	4,400	230	" "	4,600	240
" "	3,700	170	" "	11,000	320	" "	6,200	260	" "	6,200	270
" "	3,700	240	" "	12,000	330	" "	9,400	270	" "	7,800	290
" "	3,900	210	" "	12,000	350	" "	10,200	280	" "	8,600	300
" "	4,600	230	" "	12,400	350	" "	11,000	290	" "	9,400	300
" "	5,400	240	" "	12,400	410	" "	12,000	320	" "	9,800	310
" "	6,200	250	" "	12,600	360	" "	12,400	330	" "	9,800	360
" "	7,000	250	" "	12,600	480	" "	12,400	420	" "	10,000	310
" "	7,800	270	" "	13,000	400	" "	12,800	350	" "	10,000	440
" "	8,600	270	" "	13,400	560	" "	13,400	430	" "	10,600	350
" "	9,400	290	" "	13,600	*	" "	13,600	*	" "	11,000	490
" "	10,200	300	Nov. 1	2,500	120	" 22	2,500	120	" "	11,200	*
" "	11,400	320	" "	3,100	120	" "	3,000	130	" 13	2,800	130
" "	11,400	370	" "	3,400	140	" "	3,200	140	" "	3,200	130
" "	12,200	350	" "	3,500	240	" "	3,300	160	" "	3,250	130
" "	12,200	440	" "	3,600	230	" "	3,350	280	" "	3,250	280
" "	13,000	430	" "	4,000	250	" "	3,400	240	" "	3,300	230
" "	13,400	*	" "	5,400	250	" "	3,500	220	" "	3,350	220
" 11	2,500	120	" "	6,200	260	" "	4,000	220	" "	3,600	220
" "	2,900	130	" "	7,000	270	" "	4,400	230	" "	4,200	250
" "	3,300	130	" "	7,800	280	" "	6,200	240	" "	5,000	250
" "	3,500	190	" "	9,400	280	" "	7,000	270	" "	7,000	250
" "	3,600	220	" "	10,200	300	" "	7,800	280	" "	8,600	270
" "	3,900	210	" "	11,200	320	" "	8,600	280	" "	10,200	290
" "	4,600	230	" "	11,200	360	" "	9,400	290	" "	10,200	320
" "	5,400	240	" "	11,800	340	" "	9,400	320	" "	10,800	300
" "	6,600	270	" "	11,800	430	" "	10,200	320	" "	10,800	420
" "	7,800	290	" "	12,200	360	" "	10,200	440	" "	11,200	330
" "	8,600	290	" "	12,200	630	" "	10,400	340	" "	11,400	380
" "	9,400	300	" "	12,600	410	" "	10,400	490	" "	11,600	*
" "	10,200	330	" "	12,800	440	" "	10,600	370	" 20	2,900	120
" "	10,200	400	" "	13,000	*	" "	10,800	400	" "	3,100	150
" "	10,800	370	" 8	2,500	120	" "	11,000	430	" "	3,200	280
" "	10,800	530	" "	3,200	130	" "	11,200	480	" "	3,300	230
" "	11,400	410	" "	3,300	150	" "	11,400	*	" "	4,200	240
" "	11,800	550	" "	3,350	210	" 29	2,500	120	" "	4,800	250
" "	12,000	*	" "	3,450	190	" "	3,100	140	" "	6,200	260
" 18	2,500	120	" "	3,600	240	" "	3,300	150	" "	7,800	290
" "	3,400	170	" "	4,000	220	" "	3,350	250	" "	9,400	300
" "	3,550	190	" "	4,600	240	" "	3,450	220	" "	9,400	390
" "	3,600	250	" "	6,200	250	" "	3,800	240	" "	9,800	330
" "	3,900	220	" "	7,000	260	" "	5,400	240	" "	10,200	410
" "	4,300	240	" "	8,600	260	" "	6,200	240	" "	10,400	*
" "	6,200	270	" "	9,400	270	" "	7,800	260	" 27	2,500	110
" "	9,400	280	" "	10,200	280	" "	8,600	280	" "	3,000	160
" "	12,000	300	" "	11,000	280	" "	8,600	310	" "	3,050	290
" "	12,000	330	" "	11,000	320	" "	9,400	300	" "	3,100	250
" "	13,000	320	" "	11,600	300	" "	9,400	340	" "	3,200	220
" "	13,000	400	" "	11,600	370	" "	10,400	340	" "	3,500	220
" "	13,200	330	" "	11,800	320	" "	10,400	540	" "	4,600	240
" "	13,200	430	" "	11,800	440	" "	10,800	380	" "	6,200	240
" "	13,800	380	" "	12,200	340	" "	11,000	420	" "	7,800	260
" "	14,000	420	" "	12,600	440	" "	11,200	*	" "	8,600	270
" "	14,200	*	" "	12,800	*	Dec. 6	2,500	130	" "	9,400	280
" 25	2,500	120	" 15	2,500	120	" "	2,900	130	" "	9,400	330
" "	3,200	130	" "	2,900	130	" "	3,000	140	" "	10,400	320
" "	3,450	150	" "	3,330	320	" "	3,100	170	" "	10,800	360
" "	3,500	*	" "	3,400	250	" "	3,200	130	" "	11,000	410
" "	3,550	280	" "	3,600	210	" "	3,350	240	" "	11,200	*
" "	3,650	220									

* = No value obtained.

TABLE 3—*American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for October to December, 1939*

Day	October			November			December		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	0.3	0.5	0.4	0.1	0.1	0.1	0.2	0.1	0.2
2	0.1	0.5	0.3	0.1	0.0	0.1	0.0	0.0	0.0
3	0.8	1.3	1.0	0.1	0.3	0.2	0.1	0.1	0.1
4	1.5	0.7	1.1	0.1	0.1	0.1	0.1	0.1	0.1
5	0.4	0.6	0.5	0.1	0.0	0.1	0.0	0.4	0.2
6	1.1	0.6	0.8	0.0	0.3	0.1	0.4	0.9	0.6
7	0.1	0.6	0.4	0.1	0.2	0.1	1.4	0.9	1.2
8	0.2	0.4	0.3	0.1	0.2	0.1	0.9	0.8	0.8
9	0.9	0.5	0.7	0.1	0.1	0.1	0.4	0.5	0.4
10	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.2	0.1
11	0.3	0.4	0.3	0.0	0.1	0.1	0.1	0.1	0.1
12	0.0	0.0	0.0	0.1	0.4	0.2	0.1	0.4	0.2
13	1.5	1.7	1.6	0.9	0.9	0.9	0.0	0.0	0.0
14	1.7	1.2	1.5	0.5	0.5	0.5	0.0	0.1	0.0
15	1.6	0.6	1.1	0.1	0.0	0.0	0.2	0.3	0.2
16	0.6	0.8	0.7	0.0	0.0	0.0	0.0	0.5	0.2
17	0.5	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0
18	0.5	0.7	0.6	0.1	0.0	0.0	0.0	0.0	0.0
19	0.6	0.3	0.4	0.0	0.6	0.3	0.0	0.0	0.0
20	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.2	0.1
21	0.3	0.5	0.4	0.0	0.1	0.1	0.9	0.9	0.9
22	0.1	0.4	0.2	0.0	0.0	0.0	0.7	0.7	0.7
23	0.4	0.6	0.5	0.1	0.1	0.1	0.5	0.1	0.3
24	0.1	0.1	0.1	0.1	0.6	0.3	0.4	0.1	0.2
25	0.0	0.0	0.0	0.6	0.6	0.6	0.0	0.1	0.0
26	0.0	0.3	0.1	0.6	0.3	0.4	0.0	0.1	0.1
27	0.0	0.1	0.1	0.1	0.1	0.1	0.6	0.6	0.6
28	0.1	0.1	0.1	0.1	0.0	0.0	0.3	0.5	0.4
29	0.1	0.1	0.1	0.0	0.1	0.0	0.4	0.2	0.3
30	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.0
31	0.1	0.1	0.1				0.0	0.0	0.0
Means	0.5	0.5	0.5	0.1	0.2	0.2	0.3	0.3	0.3

the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March, 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for Table 2 of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department

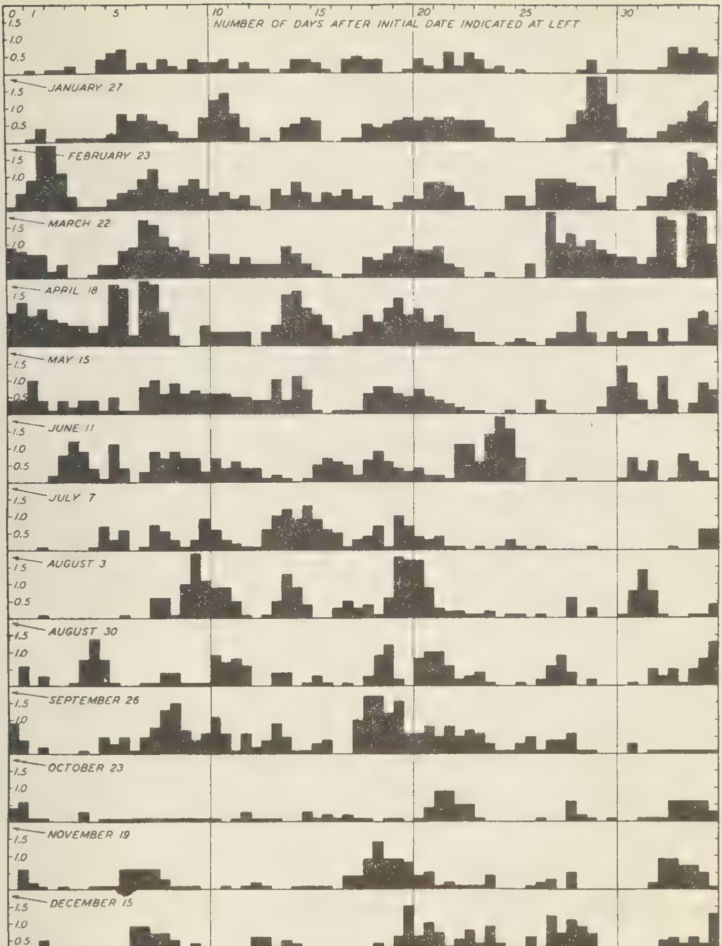


FIG 1—AMERICAN CHARACTER-FIGURE, C_A, GREENWICH HALF-DAYS IN 27-DAY SEQUENCES, 1939-1940

of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and its values for the first twelve, second twelve, and twenty-four hours of each Greenwich day for October to December, 1939, are given in Table 3.

The mean ratings of the American magnetic character-figure for the half-days by months during 1939, for the individual observatories, appear in Table 4. The average activity for the year, 0.40, does not materially differ from that for 1938, 0.38. The American magnetic character-

Table 4—*Mean magnetic character-figure assignments of individual observatories for half-days, 1939*

Observatory	Interval GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Yea
	h h													
Cheltenham	0-12	0.11	0.36	0.61	0.63	0.60	0.45	0.45	0.32	0.28	0.40	0.13	0.18	0.38
	12-24	0.08	0.30	0.53	0.70	0.47	0.42	0.42	0.31	0.28	0.26	0.08	0.13	0.33
	0-24	0.10	0.33	0.57	0.67	0.53	0.43	0.44	0.31	0.28	0.33	0.10	0.15	0.35
Honolulu	0-12	0.26	0.45	0.32	0.40	0.65	0 58	0.47	0.40	0.40	0.53	0.22	0.26	0.41
	12-24	0.26	0.45	0.32	0.38	0.56	0.38	0.37	0.37	0.30	0.42	0.19	0.23	0.35
	0-24	0.26	0.45	0.32	0.39	0.60	0.48	0.42	0.39	0.35	0.48	0.20	0.24	0.38
Huancayo	0-12	0.03	0.29	0.44	0.43	0.47	0.22	0.26	0.31	0.32	0.34	0.03	0.29	0.29
	12-24	0.34	0.57	0.56	0.77	0.48	0.28	0.39	0.39	0.37	0.50	0.42	0.53	0.47
	0-24	0.19	0.43	0.50	0.60	0.48	0.25	0.32	0.35	0.34	0.42	0.23	0.41	0.38
San Juan	0-12	0.16	0.50	0.61	0.63	0.69	0.62	0.63	0.40	0.38	0.52	0.17	0.27	0.46
	12-24	0.35	0.62	0.76	0.78	0.76	0.57	0.71	0.44	0.48	0.68	0.21	0.35	0.56
	0-24	0.26	0.56	0.69	0.71	0.73	0.59	0.67	0.42	0.43	0.60	0.19	0.31	0.51
Sitka	0-12	0.21	0.39	0.47	0.58	0.48	0.38	0.47	0.35	0.33	0.48	0.28	0.23	0.39
	12-24	0.18	0.45	0.35	0.58	0.37	0.27	0.47	0.45	0.27	0.50	0.19	0.21	0.36
	0-24	0.19	0.42	0.41	0.58	0.43	0.32	0.47	0.40	0.30	0.49	0.23	0.22	0.37
Tucson	0-12	0.11	0.39	0.61	0.65	0.71	0.55	0.44	0.31	0.27	0.40	0.08	0.21	0.39
	12-24	0.08	0.43	0.58	0.70	0.53	0.40	0.37	0.28	0.25	0.44	0.11	0.19	0.36
	0-24	0.10	0.41	0.60	0.68	0.62	0.48	0.40	0.29	0.26	0.42	0.10	0.20	0.38
Watheroo	0-12	0.37	0.68	0.53	0.55	0.40	0.35	0.44	0.29	0.33	0 50	0.10	0.27	0.40
	12-24	0.26	0.82	0.61	0.68	0.35	0.28	0.42	0.34	0.28	0.50	0.15	0.39	0.42
	0-24	0.31	0.75	0.57	0.62	0.38	0.32	0.43	0.31	0.31	0.50	0.12	0.33	0.41
Means	0-12	0.18	0.44	0.51	0.55	0.57	0.45	0.45	0.34	0.33	0.45	0.14	0.24	0.39
	12-24	0.22	0.52	0.53	0.66	0.50	0.37	0.45	0.37	0.32	0.47	0.19	0.29	0.41
	0-24	0.20	0.48	0.52	0.61	0.54	0.41	0.45	0.35	0.32	0.46	0.17	0.27	0.40

figure for each half-day for the period December 31, 1938, to January 18, 1940, is plotted in Figure 1 ordered according to 27-day sequences. The initial date of the first sequence in Figure 1 is that following the last sequence which appeared in the plot for the year 1938 on page 98 of the March 1939 number of this Journal. During 1939 the 27-day sequence of magnetic disturbance is somewhat evident following the decline in the sunspot-cycle.

H. F. Johnston

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., January 24, 1940

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY OCTOBER TO DECEMBER, 1939

Greenwich mean time						Range hor. int.
Beginning			Ending			
1939	*h*	*m*	*d*	*h*	*m*	γ
Oct. 3	08	..	4	06	..	240
13	02	05*	15	08	..	270
Dec. 6	20	07	8	22	..	140

*Sudden commencement.

Day	October 1939 K₂ Whole disk	K₂ Central zone	*Hα* bright	*Hα* dark	No. groups	Mag'c char.
1					11[f]	0
2					..	0
3					..	1
4					9[g]	1
5					9	0.5
6					9	1
7					..	0
8					9	0
9					9	0.5
10					6	0
11					5	0
12					8[g]	0
13					8	2
14					5	2
15					7[b]	1
16					7	0.5
17					6	0.5
18					8	0.5
19					8	0.5
20					8	0
21					7	0
22					10	0
23					11	0
24					..	0
25					10[g]	0
26					10	0
27	3	3	3	2	8	0
28	3	3	3	2	7[b]	0
29	3	3	3	2	8	0
30	3	2	3	1	7	0
31	3	3	3	2	8	0
Mean					8.1	0.4

Day	November 1939 K₂ Whole disk	K₂ Central zone	*Hα* bright	*Hα* dark	No. groups	Mag'c char.
1	3	3	..	..	7[b,e]	0
2	3	3	..	..	6	0
3	3	3	..	..	7	0
4	..	..	..	..	10	0
5	2	2	..	..	10	0
6	2	2	..	..	8	0
7	2	2	2	2	7	0
8	..	..	..	..	..	0
9	2	2	2	3	6	0
10	2	3	2	2	7[b]	0
11	2	2	2	2	8	0
12	2	2	2	2	7	0
13	2	2	2	3	7[b]	1
14	2	3	2	2	7	0.5
15	3	3	3	3	7	0
16	..	..	3	2	8	0
17	4	3	4	3	9	0
18	4	3	4	2	8[h]	0
19	4	3	4	2	7	0
20	4	3	3	3	5	0
21	4	4	3	3	4	0
22	3	3	3	3	4[f]	0
23	3	3	3	3	6	0
24	..	..	..	..	6	0.5
25	3	1	3	3	5	0.5
26	..	..	..	..	7[b]	0.5
27	..	..	..	..	9	0
28	3	4	3	4	5	0
29	3	3	3	3	4[f]	0
30	3	3	3	3	3	0
Mean	2.8	2.7	2.8	2.6	6.7	0.1

Day	December 1939 K₂ Whole disk	K₂ Central zone	*Hα* bright	*Hα* dark	No. groups	Mag'c char.
1	3	1	3	2	5	0
2	..	..	..	..	5	0
3	3	2	3	3	6	0
4	3	3	2	2	5	0
5	2	3	2	2	3	0
6	2	3	2	3	3	0.5
7	3	2	2	2	3	1
8	2	2	2	2	4	1
9	2	1	2	3	5[b]	0.5
10	2	2	2	3	6	0
11	..	..	..	..	8	0
12	3	3	2	3	9	0
13	3	3	3	3	9	0
14	3	3	2	2	8	0
15	3	3	3	3	7	0
16	3	3	3	2	7	0
17	3	3	3	2	8	0
18	3	3	3	2	7	0
19	3	3	3	2	7	0
20	3	2	3	2	7	0
21	3	2	3[b]	3	5	1
22	3	2	3	2	6	0.5
23	..	..	..	..	..	0
24	..	..	3	2	5	0
25	3	3	3	1	5	0
26	3	3	2	1	3	0
27	2	2	2	1	4	0.5
28	2	2	2	2	5	0
29	2	2	2	2	6	0
30	2	2	..	..	6	0
31	2	1	2	3	5[b]	0
Mean	2.6	2.4	2.5	2.2	5.7	0.2

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day. The 60-foot tower telescope was out of use from June 1 to October 26, 1939, because of alterations. For this reason no spectroheliograms are available during that period.

a, b Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

c, d Very bright chromospheric eruptions; (*c*) less than 30° from the center of the disk, (*d*) more than 30° from the center of the disk.

e, f, g, h, i, j, k, l Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

The disturbance of October 3 to 4 was not like that of a typical magnetic storm, although the range in H was large. The largest spot-group on the Sun was Mount Wilson No. 6623,[1] which crossed the central meridian on October 4.2, 14° north of the center of the disk.

The magnetic storm of October 13 to 15 was probably associated with the active group No. 6633, which crossed the central meridian on October 12.3, 12° south of the center of the disk.

At the time of the storm of December 6 to 8 only three spot-groups were present on the visible hemisphere of the Sun. The largest of these was No. 6692, which crossed the central meridian on December 7.4, 9° south of the center of the disk.

Carnegie Institution of Washington,
Mount Wilson Observatory,
Pasadena, California

Seth B. Nicholson
Elizabeth Sternberg Mulders

NOTE REGARDING RESOLUTION NO. 4, WASHINGTON ASSEMBLY, INTERNATIONAL ASSOCIATION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

Resolution No. 4 adopted in September 1939 at the Washington Assembly of the International Union of Geodesy and Geophysics as published in the December 1939 number of the Journal (p. 478) is not complete. In its final form it is as follows:

(4) *Control of variometers and absolute instruments*—(*a*) The Association reaffirms its Resolution 3 adopted at the Edinburgh Assembly of the great need of examination at regular intervals, at least every two years, of magnetic instruments, including the control of the direction of the magnetic axes of the magnets in variometers.

(*b*) The Association recommends that instruments used for the determination of declination and inclination be adjusted so that their corrections do not exceed the standard error of a single observation.

J. A. Fleming

AUX DIRECTEURS DES OBSERVATOIRES MAGNÉTIQUES, CONTRIBUANTS À LA PUBLICATION "CARACTÈRE MAGNÉTIQUE NUMÉRIQUE DES JOURS"

L'Association de Magnétisme et Electricité Terrestres de l'Union Géodésique et Géophysique Internationale a résolu, dans ses séances de septembre 1939 à Washington, de discontinuer la publication des caractères magnétiques numériques des jours, à partir de l'année 1940.

D'accord avec cette résolution, j'ai l'honneur de vous prier de ne plus envoyer vos tableaux avec les valeurs de HR_H:10000, ZR_Z:10000, et R_D après le dernier trimestre de 1939.

La publication des caractères magnétiques de chaque jour, échelle 0, 1, 2, sera continuée comme auparavant.

Institut Royal Météorolique des Pays-Bas,
De Bilt, janvier 1940

G. van Dijk

[1]Summary of Mount Wilson magnetic observations of sunspots, Pub. Astr. Soc. Pacific, **51**, 361-364 (1939); Positions and areas of sunspots, Mon. Weath. Rev., **67**, 344-346, 388-390 (1939).

PRINCIPAL MAGNETIC STORMS

(See also pages 44 and 48)

Alibag Magnetic Observatory[1]

July to September, 1939

(Latitude 18° 38′.3 N., longitude 72° 52′.3 or $4^h\,51^m.5$ E. of Gr.)

July 3-4—A moderate storm began at $00^h\,40^m$ GMT, July 3, with a sudden increase of 0′.4 in westerly D and 14 gammas in H, and a decrease of 3 gammas in Z. H began to rise slowly till $03^h\,36^m$, July 3, when there was a steep rise of 26 gammas. Thereafter it began to decrease slowly till $07^h\,16^m$, July 3, when there was a second sharp increase of 26 gammas. At $07^h\,30^m$, July 3, there was a further sudden rise of 27 gammas in H, to reach its maximum at $07^h\,32^m$, July 3. Within twelve minutes of its attaining its maximum H had a sudden fall of 47 gammas and thence a gradual fall associated with occasional fluctuations continued till the minimum was reached at $12^h\,52^m$, July 3. Disturbed conditions continued till 19^h, July 3, when quieter conditions prevailed. The disturbance ended at $08^h.5$, July 4. Ranges: D, 8′.6; H, 197 gammas; Z, 60 gammas.

July 4-5—Another moderate disturbance began at $14^h\,08^m$ GMT, July 4, with a sudden rise of 0′.7 in westerly D and 33 gammas in H, and a sharp fall of 6 gammas in Z. Gradually rising with numerous fluctuations H reached its maximum at $01^h\,45^m$, July 5, and thereafter began to fall with comparatively smaller oscillations to reach a minimum at $12^h\,55^m$, July 5. The fluctuations in H became more pronounced from $14^h.5$, July 5, and continued so till 21^h, July 5. The storm ended at about $22^h.5$, July 5. Ranges: D, 7′.6; H, 213 gammas; Z, 92 gammas.

July 11—A peculiar disturbance of short duration apparently looking like a "bay storm" commenced at $11^h\,37^m$ GMT, July 11, with a sudden increase of 0′.5 in D (westerly) and 14 gammas in H, and a fall of 5 gammas in Z. All the elements showed fluctuations till $15^h.5$, July 11, when the disturbance ended. Ranges: D, 2′.1; H, 78 gammas; Z, 18 gammas.

July 14—A moderate disturbance with a sudden increase of 21 gammas in H began at $03^h\,51^m$ GMT, July 14. H attained its maximum at $04^h\,40^m$, and the minimum at $16^h\,37^m$. The storm ended at $18^h\,30^m$. Ranges: D, 4′.3; H, 144 gammas; Z, 30 gammas.

July 19-21—A storm of moderate intensity commenced with a sudden increase of 0′.3 in D (westerly) and 31 gammas in H, and a fall of 3 gammas in Z, at $22^h\,05^m$ GMT, July 19. After attaining its maximum at $04^h\,37^m$, July 20, H fell with slight oscillations. The minimum in H occurred at $14^h\,35^m$, July 20, after which large period oscillations continued for a few hours. Minor fluctuations followed and the storm came to an end at 05^h, July 21. Ranges: D, 4′.7; H, 159 gammas; Z, 30 gammas.

July 21—A fresh moderate disturbance of short duration began at $09^h\,59^m$ GMT, July 21, with an instantaneous rise of 1′.1 in D (westerly)

[1]Communicated by Dr. S. R. Savur, Director, Bombay and Alibag Observatories.

and 29 gammas in H, and a fall of 11 gammas in Z. Reaching its maximum at $10^h\,02^m$, H decreased gradually for about forty minutes after which the fall became more steep and was associated with several small-period vibrations. At $12^h\,49^m$, H fell rapidly by 72 gammas in forty minutes to reach its minimum at $13^h\,30^m$. Immediately afterwards H had a very sharp increase of 36 gammas followed by an almost instantaneous fall of 18 gammas in four minutes. Conditions became quieter after $13^h\,40^m$, and the storm ceased at $17^h.5$. Ranges: D, 3′.6; H, 167 gammas; Z, 18 gammas.

August 12-13—Following a period of slight disturbance, a storm of great intensity commenced at $01^h\,42^m$ GMT, August 12, with an instantaneous rise of 2′.1 in westerly D and 54 gammas in H, and a sudden fall of 9 gammas in Z. Ten minutes later H attained its maximum and began to fall almost immediately. Small-period oscillations with varying amplitudes, continued till 09^h, August 14, after which the oscillations became less violent. Minimum in H occurred at $10^h\,32^m$, August 12. Later, H rose gradually and the perturbations became weaker very slowly. The main disturbance ended at 09^h, August 13, though minor fluctuations continued for several hours later. Ranges: D, 9′.0; H, 169 gammas; Z, 73 gammas.

August 16-17—A moderate disturbance commenced at $09^h\,44^m$ GMT, August 16. H fell fairly rapidly till $13^h\,52^m$, August 16, without marked fluctuations. Thereafter, it rose till 15^h, August 16, and then began to fall. The fluctuations became more pronounced and H attained its minimum at $16^h\,08^m$, August 16, after which conditions became quieter. The disturbance ended at $06^h.5$, August 17. Ranges: D, 5′.8; H, 169 gammas; Z, 50 gammas.

August 22-23—After some hours of slight activity a severe storm commenced at $00^h\,42^m$ GMT, August 22, with a sudden rise of 0′.9 in westerly D and 27 gammas in H, and a fall of 8 gammas in Z. Attaining its maximum value at $01^h\,02^m$, August 22, H began to fall with small oscillations. At $03^h\,04^m$, August 22, there was a sudden fall of 1′.9 in westerly D and 44 gammas in H, and an abrupt rise of 16 gammas in Z. This sudden movement was immediately followed by instantaneous movements in the opposite directions to the extent of 2′.6 in D (westerly), 14 gammas in H, and 14 gammas in Z. At $03^h\,34^m$, August 22, there was a sudden increase of 0′.5 in D and 28 gammas in H, and a fall of 4 gammas in Z, in three minutes. This was followed by a very rapid fall of 2′.5 in D and 88 gammas in H, and a rise of 17 gammas in Z within four minutes. Small-period vibrations continued with occasional humps till 12^h, August 22. H attained its maximum at $08^h\,32^m$, August 22, and began to fall gradually with numerous fluctuations till $10^h.5$, August 22, after which the fall became rather rapid, H decreasing by 223 gammas in 3.3 hours. The minimum in H was reached at $14^h\,34^m$, and the force began to rise with large-period fluctuations. Gradually conditions became quieter and the storm ended at $19^h.5$, August 23. Ranges: D, 10′.2; H, 283 gammas; Z, 58 gammas.

September 9—A moderate disturbance began with a gradual commencement at about 01^h GMT, September 9. H reached its large day-maximum at $04^h\,26^m$ and began to fall gradually with minor fluctuations, to reach its minimum at $13^h\,11^m$. Disturbance ended at about $17^h.5$. Ranges: D, 6′.9; H, 147 gammas; Z, 62 gammas.

September 17—A storm of moderate intensity commenced at about $02^h\,09^m$ GMT, September 17. The beginning was marked by a conspicuous, though not sudden, fall of 14 gammas in H in fifteen minutes. H rose very gradually to reach its maximum at $07^h\,58^m$ and began to fall rather slowly. After $09^h.5$ the fall in H became more rapid, being 144 gammas in 4.5 hours. At 14^h, H had a tendency to rise slowly for some time. Another rapid fall in H occurred at $15^h\,24^m$, by 90 gammas in 2.5 hours and the minimum was reached at $18^h\,06^m$. An hour later, H rose rather steeply by 81 gammas in about twenty-six minutes. Though the ranges during the disturbance were high, the oscillations were not very rapid. The storm ended at $22^h.5$. Ranges: D, $8'.1$; H, 222 gammas; Z, 74 gammas.

BOMBAY AND ALIBAG OBSERVATORIES, *Bombay, India* — D. L. CHAUDHURI, M. R. RANGASWAMI

HUANCAYO MAGNETIC OBSERVATORY

OCTOBER TO DECEMBER, 1939

(Latitude 12° 02'.7 S., longitude 75° 20'.4 or $5^h\,01^m.4$ W. of Gr.)

October 1-2—Abnormally large diurnal bays in H occurred on both October 1 and 2 with respective ranges of 326 and 314 gammas.

October 3-4—A magnetic storm featuring large fluctuations in H began at 12^h GMT, October 3, and ended at 05^h, October 4. Ranges: D, $13'.7$; H, 465 gammas; Z, 67 gammas.

October 13-15—There was a sudden commencement at $02^h\,06^m$ GMT, October 13. In two minutes D moved easterly $1'.5$, H increased 85 gammas, and Z increased 12 gammas. The magnetogram was disturbed until 07^h, October 15. Very rapid fluctuations in H were the features on October 13. The maximum value of H, 29827 gammas, was at $16^h\,25^m$, October 13, and the minimum value of H, 29260 gammas, occurred at $22^h\,11^m$, October 13. Normal ranges occurred in D and Z.

December 6-8—Beginning at 20^h GMT, December 6, the magnetogram became slightly disturbed. There were moderate fluctuations in H during the daylight hours on December 7 and 8. The disturbance ended at 19^h, December 8.

December 21—The daylight hours from 12^h to 19^h GMT, December 21, showed moderate fluctuations in H.

H. W. WELLS, *Observer-in-Charge*

APIA OBSERVATORY

OCTOBER TO DECEMBER, 1939

(Latitude 13° 48'.4 S., longitude 171° 46'.5 or $11^h\,27^m.1$ W. of Gr.)

October 2-3—From 09^h GMT, October 2, the H-trace became disturbed and failed to rise to the usual maximum at about 23^h. A steady decline in value commenced shortly after 01^h, October 3, and a minimum value of approximately 34700 gammas was recorded at $03^h\,44^m$. Z was similarly affected but D was only very slightly disturbed. After the minimum value on October 3 the trace slowly returned to normal.

October 13-15—At $02^h\,04^m$ GMT, October 13, a sudden commencement which amounted to 39 gammas in H and 18 gammas in Z was recorded. D was affected also and showed an increase of $1'.3$ in an easterly direction.

The maximum of the disturbance occurred at $13^d\ 02^h\ 20^m$ when the value of H was 34972 gammas. From this time H decreased steadily with many rapid oscillations: but due to the normal diurnal variations being superimposed three minima occurred in H and these were approximately equal to 34709 gammas at $13^d\ 22^h\ 09^m$, 34695 gammas at $14^d\ 08^h\ 00^m$, and 34717 gammas at $15^d\ 05^h\ 08^m$. The Z-trace showed corresponding fluctuations but in the case of this element the effect of diurnal variation was much more marked and in consequence the absolute maximum and minimum of the vertical-intensity record did not correspond to those on the horizontal-intensity trace. The magnetic elements had returned to normal by the end of the 15th.

December 6-7—From a value of approximately 34917 gammas at $20^h\ 09^m$ GMT, December 6, H commenced to decrease in value instead of rising to the usual maximum. This fall continued to a minimum value of approximately 34793 gammas at $03^h\ 38^m$, December 7. The trace near the period of the minimum value showed large slow o cillations while after these had subsided a sudden increase was recorded at $08^h\ 15^m$. This amounted to 29 gammas in H and 10 gammas in Z. After this the traces returned to normal.

H. Bruce Sapsford, *Acting Director*

Watheroo Magnetic Observatory

October to December, 1939

(*Latitude 30° 19'.1 S., longitude 115° 52'.6 or $7^h\ 43^m.5$ E. of Gr.*)

October 13-15—A disturbance of moderate intensity began with a sudden commencement at $02^h\ 04^m$ GMT, October 13. The following sudden changes occurred: Westerly declination increased by 6'.0; H increased by 20 gammas; the numerical value of Z increased by 24 gammas. During the ensuing half-hour very rapid fluctuations of moderate amplitude occurred, after which the movements were more subdued, almost calm conditions occurring between 11^h and 14^h, October 13. After this time the movements became much more irregular and of larger amplitude, the minimum value in H being reached at $03^h\ 40^m$, October 14. The period of greatest activity was from 09^h to 15^h, October 14. A quieter period of nine hours followed after which there were eight hours of considerable activity, the most disturbed portion of this period being from 03^h to 08^h, October 15. From that time the elements quickly resumed their normal values. Ranges: D, 27'; H, 256 gammas; Z, 238 gammas.

W. C. Parkinson, *Observer-in-Charge*

Magnetic Observatory, Capetown

July to September 1939

(*Latitude 33° 57' S., longitude 18° 28' or $1^h\ 13^m.9$ E. of Gr.*)

Note: D and Z are negative; changes are in the algebraic sense.

July 3—A small storm began with a sudden commencement at $00^h\ 40^m$ GMT, July 3. At about $03^h\ 55^m$ bays developed in the three traces and also at about $18^h\ 30^m$ larger bays with peaks occurred. The ranges of the larger bays were $\pm 10'$ in D, $+42$ gammas and -26 gammas in H, and the numerical value of Z decreased 56 gammas and increased 24 gammas. The storm ended at 24^h.

July 4-6—A storm commenced gradually at about 13^h GMT, July 4, and continued until 04^h, July 6. There were marked bays at 20^h, July 4, 16^h, July 5, and 03^h 40^m, July 6.

July 19-20—A small storm began with a sudden commencement at 09^h 03^m GMT, July 19, and continued until 22^h, July 20.

July 21—A small storm began with a sudden commencement at 09^h 58^m GMT, July 21. There was an increase of 21 gammas in five minutes in H. The storm lasted until about 18^h.

August 11-13—A storm started gradually at 12^h GMT, August 11. At 22^h the intensity of the storm increased considerably, the major disturbances dying down at about 07^h, August 12. Minor disturbances continued until 21^h, August 13.

August 16—A storm commenced gradually at 10^h GMT, August 16. There were marked bays at 13^h and 23^h.

August 21-23—Following a few preliminary oscillations, H suddenly increased by 15 gammas in four minutes at 21^h 20^m GMT, August 21. At 00^h 40^m, August 22, the changes in D were 4′ in two minutes and +34 gammas in three minutes in H. At 03^h 01^m the changes were −4′ in two minutes in D, and −31 gammas in two minutes in H. At 03^h 37^m the changes were −10′ in three minutes in D, and −47 gammas in four minutes in H. The storm continued until 24^h, August 23, with many bays in all traces. There was a remarkable bay on August 22 when the following changes occurred: At 22^h 05^m D changed +21′ in twenty minutes and −13′ in twenty minutes; at 19^h 42^m H changed +89 gammas in thirty-three minutes and −78 gammas in sixty-five minutes; at 19^h 44^m the numerical value of Z decreased 120 gammas in thirty-six minutes and increased 72 gammas in seventy-seven minutes.

September 2-4—A small storm started at 21^h 44^m GMT, September 2, with a sudden commencement during which D changed +3′ in four minutes and H changed +37 gammas in five minutes. The main disturbance lasted until about 12^h, September 3, with minor disturbances continuing until about 03^h, September 4.

September 17-18—A storm commenced gradually at about 09^h GMT, September 17. H showed the following changes, from 09^h 25^m to 14^h 00^m −84 gammas, from 14^h 00^m to 15^h 15^m +21 gammas, from 15^h 15^m to 18^h 40^m −141 gammas, from 18^h 40^m to 19^h 21^m two complete oscillations of small amplitude, from 19^h 21^m to 19^h 56^m +84 gammas, and from 19^h 56^m to 20^h 20^m −26 gammas. The following changes were recorded in D, from 19^h 05^m to 19^h 40^m −15′, and from 19^h 40^m to 20^h 10^m +11′. The numerical value of Z increased 128 gammas from 12^h 45^m to 18^h 25^m, decreased 16 gammas from 18^h 25^m to 19^h 10^m, increased 32 gammas from 19^h 10^m to 19^h 35^m, and decreased 104 gammas from 19^h 35^m to 20^h 05^m. The storm ended at about 02^h, September 18.

September 19-20—The period from 10^h GMT, September 19, to 20^h, September 20, was moderately disturbed.

TRIGONOMETRICAL SURVEY OFFICE, *Capetown, South Africa*

A. OGG, *Magnetic-Survey Adviser*

(See also page 91)

6. *Personalia*—Lieutenant Commander *G. C. Jones*, who spent several months in the Washington Office of the U. S. Coast and Geodetic Survey studying observatory methods, sailed February 8, 1940, to relieve about March 7, 1940, Commander *H. A. Cotton*, in charge of the Magnetic and Seismological Observatory at San Juan, Puerto Rico. Lieutenant Commander Jones has commanded various of the Survey's vessels since 1924, the most recent being the *Discoverer* working in Alaskan waters. It was he that sighted and rescued the Chinese junk *Tai Ping* off Vancouver Island in 1939, after Captain Anderson and crew had been at sea 105 days and unreported for 75 days. Commander Cotton, in charge of the Observatory since July 16, 1937, will return to sea-duty as commander of the Survey Ship *Lydonia*.

We regret to record the death, on February 3, 1940, of *Charles Raymond Duvall*, at his home in Washington, D. C., aged 71 years. After postgraduate work in mathematics and physics at the Johns Hopkins University he was engaged from 1899 to 1913 as computer at the United States Coast and Geodetic Survey. From 1913 until his retirement in 1937, he held the post of expert computer in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. During this period he assisted Dr. L. A. Bauer in his analysis of the Earth's magnetic field and completed the reduction and compilation of the declination and its secular change in the Pacific Ocean based on the observations of the *Galilee* and the *Carnegie*. He was unusually helpful in assisting the younger men in the Department of Terrestrial Magnetism, instructing them in methods of reduction of observations and in simplifying and systematizing methods of computation. He also took part in the computation of Peary's observations obtained during his memorable voyage of discovery to the North Pole. Mr. Duvall has to his credit a number of papers in this JOURNAL.

We regret to record the death on January 24, 1940, of Geheimer Regierungsrat Professor Dr. *Karl Haussmann* at his native town, Schwäbisch-Gmünd, in Württemberg, Germany, in his eightieth year. He was one of the outstanding representatives of terrestrial magnetism in Germany having taken a prominent part in forwarding magnetic surveying and mapping in that country. As Professor of Geodesy in the Technische Hochschulen at Aachen and Berlin, he did pioneer work in applying geophysical methods to mining problems.

7. *Three-hour-range index*—In addition to the American magnetic character-figures broadcast weekly in the cosmic-data ursigrams, since February 1, 1940, these ursigrams have included the three-hour-range index (K) described in the December 1939 number of this JOURNAL, which indicates the geomagnetic activity on the scale zero (very quiet) to 9 (extremely disturbed), a magnetic storm being characterized by $K=5$ or higher. The figure K in the broadcast describes the eight three-hour intervals of the Greenwich day ending at 19^h Eastern Standard Time prior to the day of issue; it is based on records of the Cheltenham Observatory of the United States Coast and Geodetic Survey. This index is preliminary in the sense that it will be supplemented by the results of other observatories but in view of the uniformity of the K-indices all over the Earth, the Cheltenham indices will provide prompt information which will be useful in current geophysical studies.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Archenhold, G. H. The influence of the variability of the mean latitude of sunspots on the recurrence tendency of magnetic disturbances. London, Mon. Not. R. Astr. Soc., **99**, 723-729 (1939).

Azores, Service Météorologique. Résultats des observations magnétiques pendant l'Année Polaire 1932-1933. Angra do Heroismo, Tip. Angrense, 45 pp. (1939). [Contains hourly values of the declination August 1932 to August 1933 and absolute values of inclination and horizontal intensity on certain days at the Magnetic Observatory of San Miguel.]

Bartels, J. Das Nordlicht vom 24.-25. Februar 1939 in Deutschland und die erdmagnetischen Störungen in Niemegk. Beitr. Geophysik, **55**, Heft 2, 193-203 (1939).

Potsdamer erdmagnetische Kennziffern. 5. Mitteilung. Zs. Geophysik, **15**, Heft 5/6, 333-335 (1939).

Bartels, J., N. H. Heck, and H. F. Johnston. The three-hour-range index measuring geomagnetic activity. Terr. Mag., **44**, No. 4, 411-454 (1939).

Bartels, J., and H. F. Johnston. Main features of daily magnetic variations at Sitka, Cheltenham, Tucson, San Juan, Honolulu, Huancayo, and Watheroo. Terr. Mag., **44**, No. 4, 455-469 (1939).

Bombay and Alibag Observatories. Magnetic, meteorological, atmospheric electric and seismographic observations, made at the Government Observatories, Bombay and Alibag in the year 1937, under the direction of K. R. Ramanathan. Reduced and tabulated under the direction of K. R. Ramanathan and S. R. Savur. Delhi, Manager of Publications, xv+A-76+B-44+C-4+D-13 with 5 pls. (1939).

Canada, Meteorological Services. Canadian Polar Year expeditions 1932-33. Volume II. Terrestrial magnetism, earth-currents, aurora borealis. Chesterfield Inlet, Meanook, Saskatoon. Ottawa, 185 pp., 3 pls., 27 figs. (1939). 32 cm. [Contains: Magnetic results of Polar Year expedition to Chesterfield Inlet; Magnetic observations at field-stations (Baker Lake and Dead Man Island) August 1933; Magnetic results of Polar Year Observations at Meanook; Earth-current observations at Chesterfield Inlet; Measurements of the height of the aurora borealis at Saskatoon, Canada, 1932-33; Report on auroral height measurements and observations at Chesterfield Inlet, Canada.]

Chapman, S. Two new books on terrestrial magnetism and electricity: A review and a preview. Terr. Mag., **44**, No. 4, 383-388 (1939). [The two books reviewed are: "Terrestrial Magnetism and Electricity" edited by J. A. Fleming, and "Geomagnetism" by S. Chapman and J. Bartels.]

Coimbra. Observações meteorológicas, magnéticas e sismológicas feitas no Instituto Geofísico (Observatório Meteorológico, Magnético e Sismológico) no ano de 1937. 2ª Parte—Magnetismo terrestre. Vol. LXXVI. Coimbra, Tip. da Gráfica de Coimbra, 6 pp. (1938).

Copenhagen, Det Danske Meteorologiske Institut. Magnetisk aarbog. 2den del: Grönland—Annuaire magnétique, 2ème Partie; Le Grönland. 1932 et 1933. Köbenhavn, G. E. C. Gad, 22+xxvii; 9+xxvii (1939). 32 cm.

De Bilt, Institut Météorologique Royal des Pays-Bas. Caractère magnétique des années 1890-1905. Moyennes diurnes, mensuelles et annuelles. Jours calmes et jours troublés. De Bilt, 20 pp. (1938). 24 cm. [Published under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.]

Dijk, G. van. The magnetic character of the year 1938, review of the years 1928-1938, and the numerical magnetic character of days 1938. Terr. Mag., **44**, No. 4, 391-393 (1939).

Magnetic character for the year 1938. Terr. Mag., **44**, No. 4, 491 (1939). [Corrections to be applied to "Caractère magnétique de l'année 1938."]

Ferri, F. La nuova rete magnetica d'Italia con una carta delle isogone al 1 luglio 1938. Atti Soc. ital. Prog. Sci., **5**, 275-286 (1939). [In 1932-1938 the Military-Geographical Institute of Florence made a new magnetic survey of Italy. A report on this work and its first results is given. An isogonic map for the epoch July 1, 1938 is reproduced. Information is also communicated on the activity of the Institute in Lybia. A table of values of the declination at the principal cities in all the Italian provinces for July 1, 1938, is included.]

Fleming, J. A. Vagaries of the Earth's magnetism. Gen. Elec. Rev., **42**, No. 10, 418 (1939). [Abstract of a General-Electric Forum talk.]

Godart, O. World-wide variations of the Earth's magnetic field and the intensity of cosmic radiation. Phys. Rev., **56**, No. 11, 1074-1077 (1939).

Hongkong, Royal Observatory. Magnetic results 1938. Prepared under the direction of C. W. Jeffries, Director. Hongkong, Noronha and Co., Govt. Printers, 51 pp. (1939).

India, Survey of. Geodetic report 1938. Published by order of Brigadier C. G. Lewis, Surveyor General of India. Dehra Dun, Geod. Branch Office, v+86, 1 pl., 11 charts (1939). 26 cm. [Contains brief report on magnetic observations at Dehra Dun with tables giving monthly mean values of the magnetic elements for 1936 and 1937 with annual changes during the period; the mean hourly deviations from the monthly means; classification of the magnetic character of all days of 1937.]

Jackson, W. E. W. Agincourt magnetic data 1899-1937 and the sunspot cycle. J. R. Astr. Soc. Canada, **33**, No. 10, 401-414 (1939).

Jones, W. M. Magnetic observations in the Onekaka-Parapara District with some remarks on the geology of the iron-ore deposits. N. Z. J. Sci. Tech., Wellington, B, **21**, 16b-30b (1939).

Magnetic surveys in North Auckland. N. Z. J. Sci. Tech., Wellington, B, **21**, [illegible] (1939). [The results are described of some surveys of the variations of vertical intensity in parts of North Auckland. The regional anomaly previously found to extend between [illegible] and [illegible] was found to connect directly to the Maungaru-Tangihua doleritic body, and is considered to be due to the extension southwards below the surface of this type of rock. Areal anomalies were also located in the Kaukapakapa-Silverdale district. The possibilities of application of magnetic survey to some practical problems, especially structural geology and water-supply, are discussed.]

[illegible], J. Ueber Polarlichter und magnetische Stürme. Elektrot. Zs., **60**, No. 17, 509-510 (1939).

Kreutzer, K. Die magnetischen Einheiten im Magnetkompasswesen. Seewart, **8**, 277-283 (1939).

Labrouste, M. et Mme H. Étude statistique du cycle undécennal de la composante diurne de la déclinaison magnétique. Paris, C.-R. Acad. sci., **209**, 565-568 (1939).

Étude statistique du cycle undécennal de la déclinaison magnétique. Paris, C.-R. Acad. sci., **209**, 689-691 (1939).

Lahaye, E. La déclinaison magnétique à Uccle en septembre 1939. Ciel et Terre, **55**, No. 12, 456-457 (1939).

Nagata, T. A "free-air" reduction of local magnetic anomalies. Bull. Earthquake Res. Inst., Tokyo Imp. Univ., **17**, Pt. 2, 411-422 (1939).

Newton, H. W. Sunspots, bright eruptions, and magnetic storms. Observatory, **62**, No. 787, 318-326 (1939).

New Zealand. Thirteenth annual report of the Department of Scientific and Industrial Research. Wellington, E. V. Paul, Govt. Printer, 132 pp. (1939). 35 cm. [This report covers year 1938-39, and contains reports on the Apia Observatory, Samoa, by H. B. Sapsford, and on the Magnetic Observatory, Christchurch, by H. F. Skey, pp. 123-126.]

Ógyalla. Bulletin mensuel de l'Observatoire Royal pour la Météorologie et le Magnétisme terrestre à Ógyalla, janvier à avril 1939. Budapest, Obs. R. Mét. Mag. Terr., **1**, Nos. 1-4, pp. 1-40 (1939). [These first four numbers of the new series contain results of potential-gradient observations and departures of the hourly values of magnetic declination from the monthly mean.]

Principal Magnetic Storms. July to September, 1939. Terr. Mag., **44**, No. 4, 399-400, 470, 491-496 (1939). [Storms reported by Apia Observatory are for April to September, 1939, those by Watheroo Magnetic Observatory are for June to September, 1939, and those by the Magnetic Observatory, Capetown, are for April to June, 1939.]

Schmidt, Ad. Zur Frage der hypothetischen die Erdoberfläche durchdringenden elektrischen Ströme. Mit einem Zusatz von J. Bartels. Beitr. Geophysik, **55**, Heft 2, 292-302 (1939). [The history of the vertical currents, derived from geomagnetic observations, is briefly discussed. The assumption, that these currents are not real, but only a consequence of remaining errors in the observations, is supported by a detailed comparison of these currents for the epochs 1885 and 1922. The average hypothetical current-densities decrease by more than one third from 1885 to 1922, owing to the improved observational material; their geographical distribution is quite different for the two epochs. The nature of the errors and the means for their elimination are discussed.

Tromsö, Auroral Observatory. Results of magnetic observations for the year 1938. By L. Harang and E. Tönsberg. Bergen, Pub. Inst. Kosmisk Fysikk, No. 17. 31 pp. (1939).

Vacquier, V. A proposed geophysical method for orienting cores. Geophysics, **4**, No. 4, 292-299 (1939). [A new method of orienting cores is suggested, in which a fluid suspension of magnetic particles is made to solidify and adhere firmly to the formation at the bottom of the well. While the substance is still liquid, the magnetic particles line up in the direction of the Earth's magnetic field so that upon solidifying a magnetized body is tightly cemented to the rock. The formation is then cored and the topmost core carrying an inclusion of the polarized material is oriented by means of a magnetometer. When such a core is recovered there can be no doubt as to the fidelity of the result.]

B—Terrestrial and Cosmical Electricity

Alfvén, H. On the origin of cosmic radiation. Phys. Rev., **56**, No. 10, 1060 (1939).

Auger, P., et J. Daudin. La partie pénétrante des grandes gerbes de rayons cosmiques. Paris, C.-R. Acad. sci., **209**, No. 12, 481-483 (1939).

Auger, P., P. Ehrenfest, R. Maze, J. Daudin, Robley, and A. Fréon. Extensive cosmic-ray showers. Rev. Modern Phys., **11**, 288-291 (1939).

Auger, P., R. Grégoire, R. Maze, et B. Goldschmidt. Changements d'intensité et de composition des rayons cosmiques avec la latitude magnétique. Paris, C.-R. Acad. sci., **209**, No. 22, 794-797 (1939).

Auger, P., and T. Grivet. Analysis of deep rays. Rev. Modern Phys., **11**, 232-234 (1939).

Auger, P., Robley, et Pluvinage. Les variations des grandes gerbes de rayons cosmiques en fonction de la pression barométrique, de l'altitude et du temps. Paris, C.-R. Acad. sci., **209**, No. 14, 536-537 (1939).

Baños, A., Jr., H. Uribe, and J. Lifshitz. Stable periodic orbits in the theory of primary cosmic radiation. Rev. Modern Phys., **11**, 137-148 (1939).

Berry, S. S. A noteworthy aurora. Science, **90**, 490-491 (Nov. 24, 1939). [Description of aurora of August 11, 1939.]

Blackett, P. M. S. Cosmic rays. The thirtieth Kelvin lecture. J. Inst. Elec. Eng., **85**, 681-684 (1939).

Blackett, P. M. S., and B. Rossi. Some recent experiments on cosmic rays. Rev. Modern Phys., **11**, 277-281 (1939).

Bonnal, P. Sur l'aurore boréale du 13 octobre 1939. Paris, C.-R. Acad. sci., **209**, 695-696 (1939); Bur. soc. astr. France, **53**, 445-446 (1939). [La note est accompagnée d'une remarque de M. Ch. Maurain sur une forte perturbation magnétique qui s'est produite en même temps que l'aurore boréale observée par M. Bonnal.]

Bothe, W. Narrow cosmic-ray showers. Rev. Modern Phys., **11**, 282-287 (1939).

Bricard, J., et J. Jung. Mesures de l'intensité de la radiation pénétrante tellurique en Auvergne. Paris, C.-R. Acad. sci., **209**, No. 12, 485-488 (1939).

Brode, R. B. The specific ionization of high speed particles. Rev. Modern Phys., **11**, 222-229 (1939).

Chapman, F. W. Atmospheric disturbances due to thundercloud discharges: Part I. Proc. Phys. Soc., **51**, No. 287, 876-894 (1939).

Clay, J. The absolute value of cosmic-ray ionization at sea level in different gases. Rev. Modern Phys., **11**, 123-127 (1939).

The intensity of cosmic radiation under thick layers. Rev. Modern Phys., **11**, 128-135 (1939).

Clay, J., and E. M. Bruins. Variations of cosmic-ray intensity with variation of barometric pressure and temperature at sea level. Rev. Modern Phys., **11**, 158-159 (1939).

Cocconi, G. A new proof of the instability of the mesotron. Phys. Rev., **57**, No. 1, 61-62 (1940).

Currie, B. W. Earth-currents. J. R. Astr. Soc. Can., **33**, No. 8, 313-323 (1939).

Dauzère, C. Sur la répartition géographique de la foudre et de la grêle dans le département de l'Ariège. Paris, C.-R. Acad. sci., **209**, No. 24, 896-897 (1939).

Forbush, S. E. World-wide changes in cosmic-ray intensity. Rev. Modern Phys., **11**, 168-172 (1939).

Fritsch, V. Grundzuge der Funkgeologie. Braunschweig, Friedr. Vieweg und Sohn. viii+121 mit 90 Abb. (1939). 22 cm. [Sammlung Vieweg, Heft 116.]

Gill, P. S. Time distribution of cosmic-ray bursts. Phys. Rev., **56**, No. 7, 632-634 (1939).

Hess, V. F. The significance of variations in cosmic-ray intensity and their relation to solar, earthmagnetic and atmospheric phenomena. Rev. Modern Phys., **11**, 153-157 (1939).

Hogg, A. R. The intermediate ions of the atmosphere. Proc. Phys. Soc., **51**, No. 288, 1014-1027 (1939). [Evidence is produced to show that (*a*) the smaller nucleated ions in city air exist in separate groups with distinct mobilities; (*b*) the variation of the mobility of these ions with humidity is such as to lead to the conclusion that the ions are composed of droplets of sulphuric acid [illegible] it appears that the ions result from the aggregation of particles containing about 2200 molecules of sulphuric acid or multiples thereof. The acid, before and after aggregation, is hydrated to an extent dependent on the temperature and the humidity of the atmosphere and on the radius of the droplet.]

Humphreys, W. J. On the origin and distribution of thunderstorm electricity. Mon. Weath. Rev., **67**, No. 9, 321 (1939).

Johnson, T. H. Evidence that protons are the primary particles of the hard component. Rev. Modern Phys., **11**, 208-210 (1939).

Jones, H. Energy distribution and positive excess of mesotrons. Rev. Modern Phys., **11**, 235-238 (1939).

Korff, S. A. Recent studies at high elevations. Rev. Modern Phys., **11**, 211-221 (1939).

Solar influences on the cosmic-ray intensity at high elevations. J. Frank. Inst., **229**, No. 1, 21-27 (1940).

Korff, S. A., and E. T. Clarke. Upward radiation produced by cosmic rays at high altitudes. Phys. Rev., **56**, No. 7, 704 (1939).

Kruijff, J. P. H. de. Meting van electrische lading van regen te Soerabaia. Nat. Tijdschr. Nederl.-Ind., **98**, No. 6, 310-319 (1938).

Loughridge, D. H., and P. Gast. Air-mass effect on cosmic-ray intensity. Phys. Rev., **56**, No. 11, 1169-1170 (1939).

LOVELL, A. C. B., AND J. G. WILSON. Investigation of cosmic-ray showers of atmospheric origin, using two cloud chambers. Nature, **144**, 863-864 (Nov. 18, 1939).

MILLIKAN, R. A., AND H. V. NEHER. New evidence for a change with time of the total energy brought into the Earth by cosmic rays. Phys. Rev., **56**, No. 6, 491-493 (1939).

MILLIKAN, R. A., H. V. NEHER, AND D. O. SMITH. Seasonal cosmic-ray effects at sea level. Phys. Rev., **56**, No. 6, 487-490 (1939).

MONK, A. T., AND A. H. COMPTON. Recurrence phenomena in cosmic-ray intensity. Rev. Modern Phys., **11**, 173-179 (1939).

MONTGOMERY, C. G., AND D. D. MONTGOMERY. The transition effect for large bursts of cosmic-ray ionization and the number of primary electrons of very high energy. Phys. Rev., **56**, No. 7, 640-643 (1939).

The behavior of high energy electrons in the cosmic radiation. Rev. Modern Phys., **11**, 255-264 (1939). Discussion (264-266).

MONTGOMERY, C. G., W. E. RAMSEY, D. H. COWIE, AND D. D. MONTGOMERY. Slow mesons in the cosmic radiation. Phys. Rev., **56**, No. 7, 635-639 (1939).

NEDDERMEYER, S. H., AND C. D. ANDERSON. Nature of cosmic-ray particles. Rev. Modern Phys., **11**, 191-207 (1939).

NORDHEIM, L. W. On the production of the hard component of the cosmic radiation. II. Protons or neutral particles as primaries. Phys. Rev., **56**, No. 6, 502-507 (1939).

NORDHEIM, L. W., AND M. H. HERB. On the production of the hard component of the cosmic radiation. I. The photon hypothesis. Phys. Rev., **56**, No. 6, 494-501 (1939).

OGASAHARA, K. Electric polarization and field intensity in the atmosphere. Discussion on the problem why potential-gradient is generally found low in the Pan-Pacific Regions. Taihoku, Inst. Met. Geophys., Taihoku Imp. Univ., 15 pp. (1939).

PHILIP, A. R. Auroral notes for August, 1939. Met. Mag., **74**, No. 886, 267-268 (1939).

POMERANTZ, M. A. The instability of the meson. Phys. Rev., **57**, No. 1, 3-12 (1940).

RAKUTTIS, G. Untersuchungen über die Richtungsverteilung und Durchdringungsfähigkeit der bei den Ultrastrahlungsstössen wirksamen Strahlen. Zs. Physik, **114**, Heft 5/6, 318-341 (1939).

RAU, W. Die Intensitätsschwankungen der harten Komponente der kosmischen Ultrastrahlung. Zs. Physik, **114**, Heft 5/6, 265-296 (1939).

RIBNER, H. S. An experimental test of Schremp's theory of cosmic-ray fine structure. Phys. Rev., **56**, No. 11, 1069-1073 (1939).

ROSSI, B. The disintegration of mesotrons. Rev. Modern Phys., **11**, 296-303 (1939).

ROUCH, J. Observations du champ électrique de l'atmosphère dans l'Océan Atlantique et dans l'Océan Pacifique. Paris, C.-R. Acad. sci., **209**, 564-565 (1939).

SCHEIN, M., AND P. S. GILL. Burst frequency as a function of energy. Rev. Modern Phys., **11**, 267-276 (1939).

SCHEIN, M., AND V. C. WILSON. Mesotron production in the atmosphere. Rev. Modern Phys., **11**, 292-295 (1939).

SCHREMP, E. J., AND H. S. RIBNER. On the fine structure pattern of directional cosmic-ray intensity. Rev. Modern Phys., **11**, 149-152 (1939).

SNODDY, L. B., AND J. W. BEAMS. A laboratory study of spark discharge between conducting clouds. Phys. Rev., **57**, No. 1, 63 (1940).

STÖRMER, C. Aurorae photographed in southern Norway. The Sky, New York, **4**, No. 2, 6-7 (1939).

STUHLWEISSENBURG, E. Zwei- und Dreifachkoinzidenzen bei Ultrastrahlungsstössen. Zs. Physik, **114**, Heft 5/6, 297-317 (1939).

SUCKSTORFF, G. A. Die Ergebnisse der Untersuchungen an tropischen Gewittern und einigen anderen tropischen Wettererscheinungen. Beitr. Geophysik, **55**, Heft 1, 138-185 (1939).

Swann, W. F. G. Showers produced by penetrating rays and allied phenomena. Rev. Modern Phys., **11**, 242-254 (1939).

Trumpy, B., und J. Orlin. Die Sekundärwirkung der durchdringenden Komponente der Ultrastrahlung. Forh. Norsk. Vid. selsk, **12**, No. 5, 15-18 (1939).

Vallarta, M. S. The determination of the energy spectrum of primary cosmic rays. Rev. Modern Phys., **11**, 239-240 (1939).

Vallarta, M. S., and O. Godart. A theory of world-wide periodic variations of the intensity of cosmic radiation. Rev. Modern Phys., **11**, 180-189 (1939). Discussion (189-190).

Vegard, L. Hydrogen showers in the auroral region. Nature, **144**, 1089-1090 (Dec. 30, 1939).

Wataghin, G., M. D. de Souza Santos, and P. A. Pompeia. Simultaneous penetrating particles in the cosmic radiation. Phys. Rev., **57**, No. 1, 61 (1940).

White, F. W. G., and M. Geddes. The antarctic zone of maximum auroral frequency. Terr. Mag., **44**, No. 4, 367-377 (1939).

Wilson, V. C. Nature of cosmic rays below ground. Rev. Modern Phys., **11**, 230-231 (1939).

Wollan, E. O. Present status of solar and sidereal time variation of cosmic rays. Rev. Modern Phys., **11**, 160-165 (1939).

Wormell, T. W. The effects of thunderstorms and lightning discharges on the Earth's electric field. Phil. Trans. R. Soc., **238**, 249-303 (1939).

C—Miscellaneous

Barnett, M. A. F. Edward Kidson (1882-1939). Terr. Mag., **44**, No. 4, 481-482 (1939).

Braaten, A. M. Note on early fade-out investigations. Terr. Mag., **44**, No. 4, 389-390 (1939).

Brunner, W. Provisional sunspot-numbers for July to September, 1939. Terr. Mag., **44**, No. 4, 480 (1939).

Chapman, S., and T. G. Cowling. The mathematical theory of non-uniform gases. An account of the kinetic theory of viscosity, thermal conduction, and diffusion in gases. Cambridge, University Press; New York, The Macmillan Co., xxiii+404 pp. (1939). 27 cm. [S. Chapman, whose contributions to geomagnetism are well known to the readers of this Journal, has presented in this book, written jointly with T. G. Cowling, a full account of work in a quite different field, namely, the solution of Maxwell's and Boltzmann's fundamental equations in the kinetic theory of gases. The general solution was obtained independently by Chapman and Enskog. Apart from the authentic treatment of the special subject, mathematical physicists will be interested in the vector and tensor notation described and used in the book as devised jointly by E. A. Milne and S. Chapman.]

Dieminger, W., und H. Plendl. Abnormale Erscheinung in der Ionosphäre während des Nordliches vom 24.-25. Febr. 1939. Beitr. Geophysik, **55**, Heft 2, 189-192 (1939).

Dodd, E. L. Periodogram analysis with the phase a chance variable. Econometrica, **7**, No. 1, 57-63 (1939).

Eckersley, T. L., and G. Millington. The experimental verification of the diffraction analysis of the relation between height and gain for radio waves of medium heights. Proc. Phys. Soc., **51**, No. 287, 805-809 (1939).

Emeleus, K. G., R. H. Sloane, and E. B. Cathcart. Excitation of the green auroral line of oxygen. Proc. Phys. Soc., **51**, No. 288, 978-988, 1 pl. (1939).

Fleming, J. A. Summary of the year's work, Department of Terrestrial Magnetism, Carnegie Institution of Washington. Terr. Mag., **44**, No. 4, 405-410 (1939).

Fleming, J. A., H. D. Harradon, and J. W. Joyce. Seventh General Assembly of the Association of Terrestrial Magnetism and Electricity at Washington, D. C., September 4-15, 1939. Terr. Mag., **44**, No. 4, 471-479 (1939).

FRIEND, A. W., AND R. C. COLWELL. The heights of the reflecting regions in the troposphere. Proc. Inst. Radio Eng., **27**, No. 10, 677-679 (1939).

GILLILAND, T. R., S. S. KIRBY, AND N. SMITH. Characteristics of the ionosphere at Washington D. C., August and September, 1939. Proc. Inst. Radio Eng., **27**, 677-679, 739-740 (1939).

Characteristics of the ionosphere at Washington, D. C., October, 1939, with predictions for January, 1940. Proc. Inst. Radio Eng., **27**, 789-790 (1939).

GOODALL, W. M. The solar cycle and the F_2-region of the ionosphere. Proc. Inst. Radio Eng., **27**, No. 11, 701-703 (1939).

HARRADON, H. D. List of recent publications. Terr. Mag., **44**, No. 4, 497-504 (1939).

HECK, N. H. Earth, air, and Sun. What can be learned of them from seismology and terrestrial magnetism. Scientia, **66**, 1-10 (1939).

HULBURT, E. O. Suggested observation of the zodiacal light during a total solar eclipse. Phys. Rev., **56**, No. 9, 960-961 (1939).

The *E*-region of the ionosphere during the annular solar eclipse of April 7, 1940. Terr. Mag., **44**, No. 4, 379-381 (1939).

JOHNSTON, H. F. American *URSI* broadcasts of cosmic data, with American magnetic character-figure C_A, July to September, 1939. Terr. Mag., **44**, No. 4, 487-491 (1939).

MITRA, S. K. The ionosphere over India. Zentralbl. Geophysik, **4**, Heft 8, 337-346 (1939).

MONTGOMERY, C. G., AND D. D. MONTGOMERY. A portable apparatus for recording bursts of cosmic-ray ionization. Rev. Sci. Instr., **10**, 350-351 (1939).

MONTGOMERY, H. C. Optical curve analysis. Bell Lab. Record, **18**, No. 1, 28-30 (1939).

MOSES, G. L. Magnet coils. Proportioning and testing. Product Eng., **11**, No. 1, 47-48 (1940).

MOUNT WILSON OBSERVATORY. Summary of Mount Wilson magnetic observations of sunspots for July to October, 1939. Pub. Astr. Soc. Pacific, **51**, 298-301, 361-364 (1939).

NATIONAL BUREAU OF STANDARDS. Averages of critical frequencies and virtual heights of the ionosphere, observed by the National Bureau of Standards at Washington, D. C., July to September, 1939. Terr. Mag., **44**, No. 4, 483-484 (1939).

NICHOLSON, S. B., AND E. S. MULDERS. Provisional solar and magnetic character-figures, Mount Wilson Observatory, April to September, 1939. Terr. Mag., **44**, No. 4, 484-487 (1939).

PARKINSON, W. C., AND L. S. PRIOR. The ionosphere at Watheroo, Western Australia, April, May, and June, 1939. Terr. Mag., **44**, No. 4, 401-403 (1939).

RATCLIFFE, J. A. The effect of the Lorentz polarization term in ionospheric calculations. Proc. Phys. Soc., **51**, No. 287, 747-756 (1939).

STAIR, R., AND I. F. HAND. Methods and results of ozone measurements over Mount Evans, Colo. Mon. Weath. Rev., **67**, No. 9, 331-338 (1939).

STETSON, H. T. Seventh assembly of the International Union of Geodesy and Geophysics. Sci. Mon., **49**, No. 5, 479-482 (1939).

Passing to peak of sunspots. The Sky, New York, **4**, No. 2, 9-11 (1939).

The present state of solar activity and associated phenomena. Science, **90**, 482-484 (Nov. 24, 1939).

TRUMAN, O. H. Variations of gravity at one place. Astroph. J., **89**, 445-462 (1939).

WELLS, H. W. The ionosphere at Huancayo, Peru, April, May, and June, 1939. Terr. Mag., **44**, No. 4, 395-399 (1939).

WHITE, F. W. G. The dispersion of wireless echoes from the ionosphere. Proc. Phys. Soc., **51**, No. 287, 859-864 (1939).

WHITE, F. W. G., AND T. W. STRAKER. The diurnal variation of absorption of wireless waves. Proc. Phys. Soc., **51**, No. 287, 865-875 (1939).

Terrestrial Magnetism and Atmospheric Electricity

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THE DIURNAL VARIATION AND VERTICAL DISTRIBUTION OF ATMOSPHERIC CONDENSATION-NUCLEI

BY E. A. YUNKER

Abstract—The diurnal variation of the distribution of atmospheric condensation-nuclei has been determined using a recording cloud-chamber apparatus. The results show an increase of nuclei-density with height in accordance with the suggestion of Gish and tentative vertical-density distribution-curves are proposed. The studies give further support to the convective theory of diurnal variation suggested by previous work. The variation of nuclei-density with wind-direction suggests a maritime origin for at least a portion of the nuclei.

Bradbury and Meuron [see 1 of "References" at end of paper] have shown that the diurnal variation of the density of atmospheric condensation-nuclei, previously observed by Wait [2], is primarily due to a convective process initiated by the Sun's radiation. They have suggested that the variation in density at a given level is caused by the existence of a dense layer of condensation-nuclei carried aloft by atmospheric convection incident to the warming of the Earth's surface by the Sun, followed by a subsidence of the layer when the temperature drops. Gish [3] has suggested that the diurnal cycle could equally well be explained by assuming the existence of a dense layer aloft carried down by the return branch of the same convective process. In order to determine which distribution obtains, whether there is a seasonal variation in the vertical distribution and what effect wind-direction has on the diurnal cycle, data on nuclei-density have been taken at two levels over a period of six months.

Apparatus

The cloud-chamber described by Bradbury and Meuron [1] was used. In order to insure a constantly moist piston-surface without the necessity of frequently adding water to the cloud-chamber a wick was attached to the velvet disk which covered the piston. This wick passed through a one-half-inch hole in the side of the chamber and extended into a small water-reservoir attached outside the chamber. This reservoir was kept filled with distilled water.

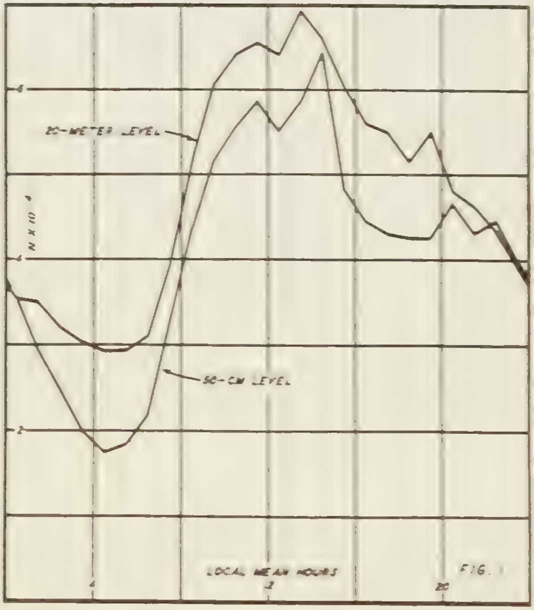
Samples of air were taken from a level 20 meters above the ground through a vertical galvanized iron pipe ten inches in diameter. A fan driven by a quarter horse-power induction-motor located at the base of the stack caused the air to move down the stack at about two meters per second. A sample was then taken off by extending the two-inch

intake pipe of the cloud-chamber into the ten-inch vertical pipe at a point about a meter above the fan. Data on the density of condensation-nuclei were taken for a level 50 centimeters above the ground and at the 20-meter level on alternate days.

The location of the apparatus employed in these experiments was the usual atmospheric-electricity observation-shelter previously employed by J. G. Brown [7] and R. A. Nielsen [8] in their experiments on space-charge, potential-gradient, atmospheric dust, and so forth. The shelter is in the middle of a large level open field covered with natural low vegetation, and well removed from buildings and traffic. The high-level intake had its opening about 17 meters above the roof of the shelter, while the low-level intake was in the side of the shelter most exposed to the prevailing wind.

Results

The average variation in condensation-nuclei density for the two levels for the period between February 1 and August 1 is shown in Figure 1. Characteristic features for the ground-level are: An early morning



minimum; a rapid increase in nuclei-density starting at sunrise and continuing to a midday maximum; a slight midday minimum shortly after noon; and a minor evening maximum. These characteristics are the same as those found by Bradbury and Meuron for the ground-level. As a further test for the explanation of the diurnal cycle as a convective process the data were divided and averaged in such a manner as to show

the effect of cloudiness, presunrise winds, and early morning high fog on the diurnal cycle. The results so obtained substantiate the work of Bradbury and Meuron and are not reproduced here.

It is seen that the nuclei-density at the 20-meter level is on the whole higher than that at the ground. The curve for the 20-meter level follows the general trend of the ground-level curve but the range in nuclei-density is less and the afternoon minimum is absent. The effect of windiness on the diurnal cycle of density at the 20-meter level is to increase the minimum density and decrease the maximum, that is, to tend to flatten out the diurnal-variation curve more than for the ground-level. This was to be expected since the wind-velocities are higher aloft than at the ground.

If the diurnal variation in nuclei-density at a given level is to be explained as a convective process, then something other than a uniform vertical distribution of nuclei must be assumed, that is, there must be a gradient of nuclei-density. The nuclei-densities for the ground-level and for the 20-meter level, as shown in Figure 1, indicate that, on the average, the nuclei-density is higher aloft than at the ground. This seems to substantiate definitely the distribution suggested by Gish. Some work by Wright [4] and by Torreson [5] indicates that the size of the atmospheric condensation-nucleus should increase with relative humidity. The fact that fog forms on condensation-nuclei in a cloud-chamber at low expansion-ratios adds plausibility to such an inference. This assumption, together with the data now presented, suggests the vertical distribution indicated in Figure 2 and the following explanation

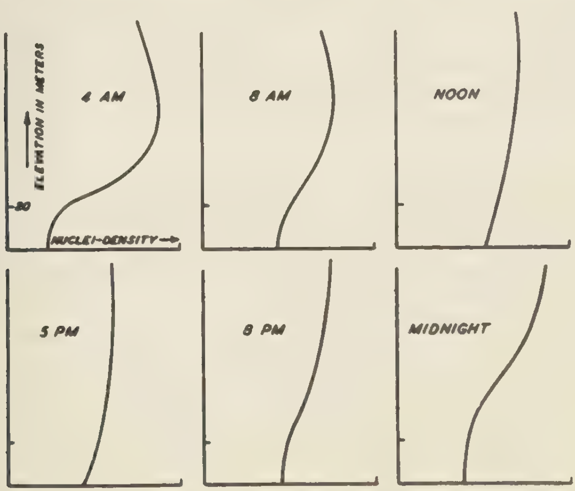


FIG. 2

of the diurnal cycle: At about four o'clock in the morning on calm days the nuclei-density is a minimum at both the ground-level and the 20-meter level and the vertical distribution is as shown with a decided

maximum in density at some upper level. The vertical scale is compressed and the actual heights involved in the upper part of the Figure are not known. However, it is known from the work of Wigand [6] that the nuclei-density falls off approximately exponentially with height above about 1000 meters. Furthermore, he has obtained evidence from balloon flights of decided nuclei-density inversions under some conditions. Also, we know that convective processes extend at least to the height of the cumulus clouds. The rise of the Sun initiates convection with the result that the density at both levels studied increases while that in the layer of maximum density above the points of observation decreases. This mixing of the upper nuclei-dense layer with the ground-layers continues until shortly after noon when the densities at both the ground-level and the 20-meter level have reached their maximum value. At the same time that the nuclei-density is being increased downward the nuclei from the layer of maximum density are being carried upward, the air of the layer being replaced by the relatively nucleus-free air from aloft. Hence, after the maximum at noon, further convection results in decreased density at both levels. Around five o'clock in the afternoon convection ceases and the nuclei start to settle downward. If now the relative humidity is higher near the ground than above, then the nuclei in the lower levels will be larger than those above and will therefore settle faster. That is, the whole system of nuclei settles earthward but those in the lower levels settle fastest and the distribution shown in Figure 2 for 4:00 A.M. is approached through the stages shown for 8:00 P.M. and for midnight. The appearance of the evening maximum in the ground-level curves is readily seen to be the result of increased nuclei-density near the ground as a result of the cessation of convection and the settling out of nuclei. It is seen that at this time the density at the two levels is about equal and that the afternoon minimum represents a true dilution-process, greater at the ground than aloft, a result which is a consequence of high-level convection.

Effect of season

In Figure 3 are shown the diurnal variations in nuclei-density for each of the months between February 1 and August 1, for both the ground-level and the 20-meter level. It is seen that the cycle for the ground-level remains essentially the same from month to month but that there are decided differences in the curves for the 20-meter level. A complete explanation of the seasonal changes in the diurnal cycle of nuclei-density should not be attempted until at least several years of records of nuclei-density at both levels are available.

Some of the differences between the curves representing the different months are probably secondary effects resulting from different types of days predominating during these different months. For example, one month may be mostly clear and calm and another largely cloudy. The winter months during which rainy and cloudy weather occurs show higher hour-by-hour ratios of density at the upper level to density at the lower than do the spring and summer months, during which clear weather predominates. This implies a steeper gradient of nuclei-density upward and probably a lower layer of maximum nuclei-density for February, March, and April than for May, June, and July. The explanation of

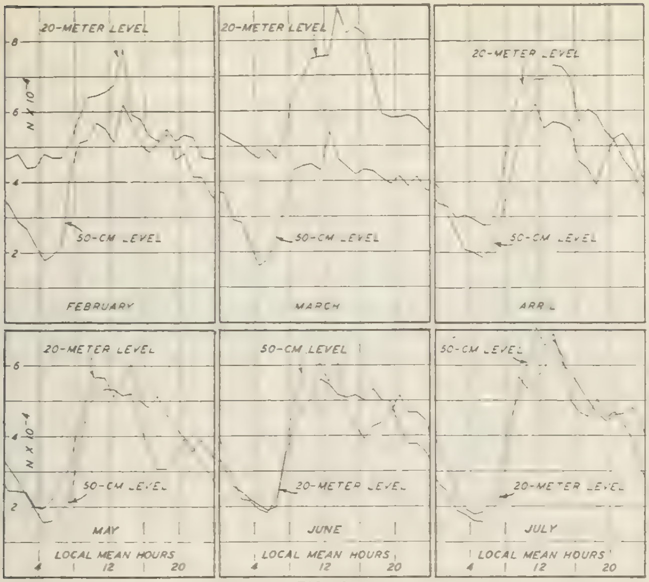


FIG. 3

the exact character of this change in level must await further data in sufficient amount to permit the necessary grouping of type of day.

The above explanation of the diurnal cycle requires the humidity during the morning hours to be higher at the ground-level than at the 20-meter level. In order to test the validity of this assumption, two hygrographs were used simultaneously, one at the ground-level and the other 20 meters above. Although one of the hygrographs proved to be unreliable and, further, the measurements were made in the unfavorable month of July, nevertheless the results indicated definitely that the period of 100 per cent humidity prior to sunrise is longer at the ground-level than at the 20-meter level, thus substantiating the hypothesis.

Effect of wind-direction

It is possible that some of the differences in the density of condensation-nuclei with season of the year might be caused by differences in the direction of the prevailing wind during the several periods. That is, the general density of nuclei might be higher when the air-flow is from certain directions rather than from others. To test this possibility, the data were arranged according to wind-direction during the hours noon to 6:00 P.M., at which time the wind, in general, blows most steadily. The ratio of the sum of nuclei-densities during this six-hour interval to the average sum for the same interval for the whole month was then taken for each wind-direction group for both ground-level and 20-meter level. These monthly values were then averaged to include the period from February 1 to August 1. The ratios are tabulated in Table 1.

TABLE 1

Direction of wind	Relative nuclei-density	
	Ground-level	20-meter level
North	1.204	1.235
Northwest	1.096	1.204
West	0.698	0.994
Southwest	0.640	0.914
Southeast	0.415	.....

It is evident that for both levels the nuclei-density is highest when the wind blows from the north and from the northwest. The geography of the region is such that a north wind at Palo Alto has had a trajectory directly over Oakland and a northwest wind directly over San Francisco. These are the only nearby industrial areas.

Thus the industrial origin of at least a part of the condensation-nuclei is strongly suggested. It is interesting to note that all air-streams from southwest to north in this locality are in general Polar Pacific air more or less modified, whereas other directions involve continental air-masses. Table 1 thus strongly suggests a maritime origin for a large fraction of the nuclei.

In conclusion, the author wishes to express his thanks to Dr. Norris E. Bradbury, under whose direction the work was done, for his many suggestions and his kindly interest. Thanks are also due the United States Weather Bureau at San Francisco for the loan of a thermo-hygrograph and to the United States Army Air Station at Sunnyvale, California, for their kindness in furnishing records of direction and speed of wind.

References

[1] N. E. Bradbury and H. J. Meuron, Terr. Mag., **43**, 231-240 (1938).
[2] G. R. Wait, Terr. Mag., **36**, 111-131 (1931).
[3] O. H. Gish, Carnegie Inst., Year Book No. 35, 253 (1937).
[4] H. L. Wright, Terr. Mag., **39**, 277-280 (1934).
[5] O. W. Torreson, Terr. Mag., **39**, 65-68 (1934).
[6] A. Wigand, Ann. Physik, **59**, 689-742 (1919).
[7] J. G. Brown, Terr. Mag., **38**, 161-173 (1933).
[8] R. A. Nielsen, Terr. Mag., **39**, 281-292 (1934).

STANFORD UNIVERSITY,
Stanford University, California

THE MOBILITY-SPECTRUM OF ATMOSPHERIC IONS

By E. A. Yunker

Abstract—The mobility-spectrum of atmospheric ions has been measured in the range of mobilities between 2.0 cm/sec/volt/cm and 10^{-3} cm/sec/volt/cm using a divided-electrode air-blast method. A continuous recording method was employed and the entire spectrum covered in about one hour. The spectrum shows the ordinary small ions, a group of ions at a mobility of about 0.5, and then a practically continuous distribution out to the lowest mobilities measured. The group having a mobility of 0.5 may be correlated with laboratory experiments of Chapman in which ions of this character were formed in the spray of dilute salt solutions. Simultaneous continuous measurements of the variation of density of condensation-nuclei lead to a lower limit for the size of the nuclei measured in the cloud-chamber of diameter 3.3×10^{-6} cm.

It is well established that atmospheric ions are qualitatively divided into three groups, the so-called small, intermediate, and large ions. It is further known that small ions (mobility 1.6) form large or Langevin ions (mobility 10^{-4}) by attachment to neutral condensation-nuclei. This presumably occurs for small ions of both signs and it has been shown [see 1 of "References" at end of paper] that the sum of the large atmospheric ions of both signs and the uncharged condensation-nuclei in a unit-volume is equal to the total number of nuclei as measured by an Aitken counter. It is not known, however, whether the small, intermediate, and large ions comprise single groups, or whether there exists a continuous range of ion-mobility. In fact the character of the ion-spectrum, as well as its diurnal variation, cannot be said to be known.

Accordingly, it has been of interest to carry out a study of this spectrum with as great a resolution as possible, and to observe at the same time its diurnal variation. These observations, coupled with simultaneous records of the density of atmospheric condensation-nuclei, make it possible to determine the size of the nuclei involved in the transition from small to large ions and furnish additional evidence concerning the character of these important atmospheric particles.

Apparatus

The method used was that of Zeleny [2] with modifications adapting it to continuous observations over a number of ranges in mobility. The outer tube A (Fig. 1) is 15.2 cm in diameter and 115.0 cm long. The

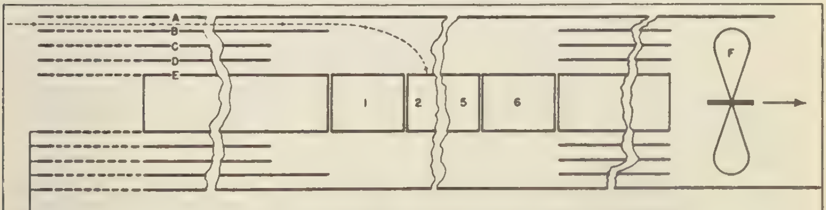


FIG. 1—SCHEMATIC DIAGRAM OF MOBILITY-SPECTRUM APPARATUS

concentric tubes B, C, D, and E at the left are insulated from each other and form annular passages through which the air enters the apparatus. A similar system of concentric tubes is mounted in the right-hand end of tube A. These are grounded while suitable accelerating potentials are applied to those on the left. The collector-electrodes 1, 2, . . . 6 are 5.0 cm in diameter and 7.5 cm long. These are insulated from their supports by means of amber blocks and connected to an electrometer-switch so that they may be, in succession, connected to an electrometer. Air is caused to move through the apparatus at constant speed by the fan F. Suitable precautions to prevent rotation in the air-streams were taken. The speed of the air was determined by means of a hot-wire thermocouple device [3].

The cycle of operation was as follows. At zero-time a potential of 200 volts with respect to ground was applied to tubes A, B, and D with tubes C and E grounded. Ions carried along by the air-stream and entering the annular passages between tubes B and C, C and D, and between D and E are swept out of the stream by the fields. Ions entering between tubes A and B, however, move in a field-free region until they reach the outlet of the passage and enter the radial field between the outer tube A and the collectors 1, 2, . . . 6. The ion then follows a path such as shown in Figure 1.

The mobility of the ion is then given by the expression

$$k = v \log(R_2/R_1)(r^2 - R_1^2)/2xV$$

where k is the mobility, v is the average velocity of the air-stream, R_2 is the inner radius of tube A, R_1 is the outer radius of the collectors, r is the distance from the axis of the apparatus to the point at which the ion enters, x is the distance from the end of the entrance-passage to the point at which the ion strikes the electrode, and V is the voltage between the outer tube A and the collector-electrodes. Collector 1 was first connected to the electrometer and charge collected for 2.5 minutes, after which the other collectors were connected in succession for equal intervals of time. The time required to cover the six collectors, including switching, was 18 minutes. For some of the measurements the electrometer-sensitivity was 2000 mm per volt, for others it was reduced to 500 mm per volt. After all of the collector-segments were covered, the potential of tubes A, B, and D was changed to 2000 volts and the collection-cycle was repeated giving six more ranges of mobility. The potentials of the tubes were then changed to 2000 volts for A, C, and D and to zero for B and E, thus allowing ions to enter between the tubes C and D, and the collectors were again connected, in succession, to the electrometer. In this manner, the mobility-range between 1.5 cm/sec/volt/cm and 4.3×10^{-3}cm/sec/volt/cm was covered in 66 minutes. By using other voltage and air-speed combinations the range was extended to 4.4×10^{-4} cm/sec/volt/cm. All switches were magnetically operated. The timing was controlled by means of cams driven by a Telechron motor.

The dotted line extensions to the tubes A to E of Figure 1 represent tubular resistors each bonded on one end to the tube to which it was attached and to a grounded ring on the other. These tubular

resistors were made by ruling 100 India-ink lines across a 16-inch strip of paper and coating the paper thickly with shellac, excepting for the space occupied by the lines. The paper was then wound on a cylindrical tube, inked lines in, while melting the dry shellac with an electric iron. The resistance of each set of lines was about 10^9 ohms. Thus the potential-gradient along each passage was made uniform and small enough so that ions entering the apparatus between the grounded rings could be carried along by the air-stream. Thus the electrode-effect at the intake of the apparatus, which would otherwise prevent ions from entering, was eliminated.

Measurements of the density of atmospheric condensation-nuclei and of the mobilities of the atmospheric ions were made simultaneously and at the same location. For the former the cloud-chamber described by Bradbury and Meuron [4] was used.

Results

Preliminary measurements using an electrometer of sensitivity 2000 mm per volt gave, for the natural positive ions, a mobility-spectrum such as shown in Figure 2. It is seen to include a band of mobilities between

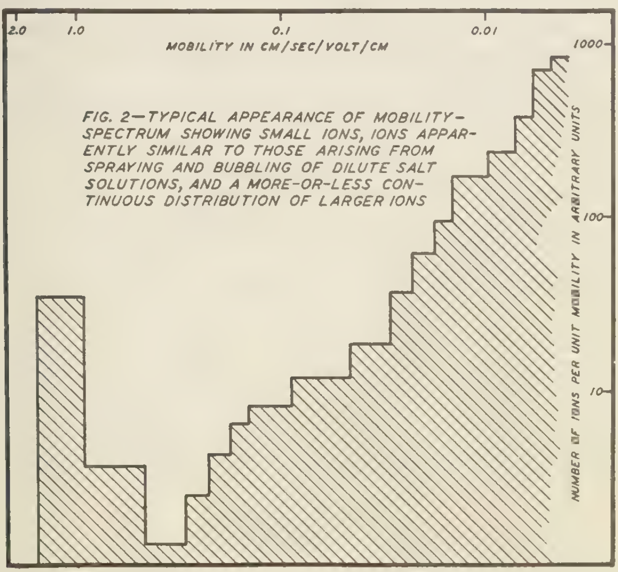
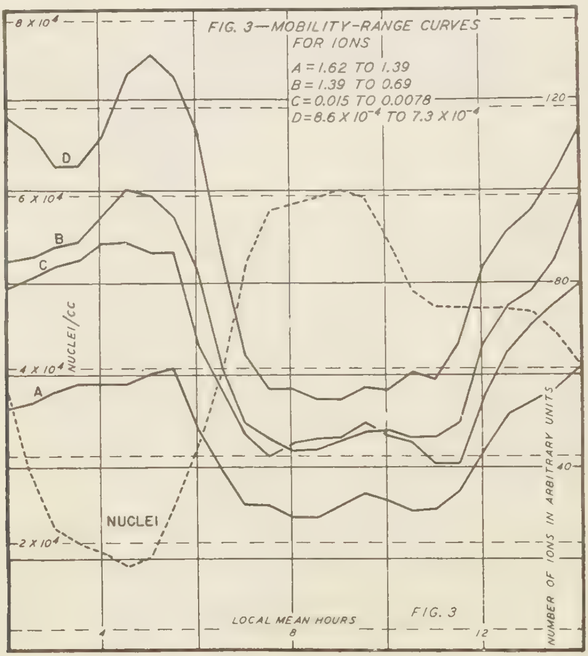


FIG. 2—TYPICAL APPEARANCE OF MOBILITY-SPECTRUM SHOWING SMALL IONS, IONS APPARENTLY SIMILAR TO THOSE ARISING FROM SPRAYING AND BUBBLING OF DILUTE SALT SOLUTIONS, AND A MORE-OR-LESS CONTINUOUS DISTRIBUTION OF LARGER IONS

1.62 and 0.9 cm/sec/volt/cm, the remaining portion of the spectrum, out to the limits studied, being structureless. The band at the high-mobility end represents the whole small-ion group invariably found in the atmosphere and designated historically as small ions. The resolving power of the apparatus was insufficient to show a structure, if it existed, for this group. The relatively large number of ions in the

range 0.9 to 0.4 cm/sec/volt/cm is of special interest because it is in this region that Chapman [5] found carrier-mobilities produced by spraying and bubbling of liquids such as distilled water, sodium iodide, lithium chloride, and potassium chloride. For positive carrier-ions mobility-"lines" were found by him at 0.35, 0.45, 0.5, and 0.75 cm sec/volt/cm, respectively. The resolution given by Chapman's apparatus, which was designed for a relatively narrow range of mobilities, is considerably greater than that used in this work. Hence a direct comparison and identification of mobility-"lines" as being due to any particular substance is impossible. It is very probable, however, that the ions found in the region 0.9 to 0.4 cm/sec/volt/cm are due to the presence of ultra-microscopic droplets of salt solutions. These may well arise as in Chapman's experiments from the evaporation of ocean-spray. This is the first observation of this class of ion in the atmosphere, it having been observed heretofore only in the laboratory.

In order to study the variations in the mobility-spectrum with respect to the variations in density of atmospheric condensation-nuclei, as well as the effect of age on the ions, the supply of atmospheric ions was augmented by the use of polonium placed inside of a large pipe through which the air passed to the mobility-apparatus. This made possible a reduction in the sensitivity of the electrometer to 500 mm per volt. Figure 3 shows a typical variation in density of condensation-nuclei with respect to the number of ions in several ranges of mobility.



It is seen that the number of ions in a range of mobilities varies, for all ranges, inversely as the density of the atmospheric condensation-nuclei. From a study of the mobility-spectra for different times of day and for different ages of ions, the following conclusions were reached:

(1) Atmospheric ions exist in all sizes, throughout the portion of the spectrum studied. However, the more massive ions tend to predominate and the ions having masses somewhat greater than those corresponding to Chapman's carrier ions are relatively infrequent. This indicates that the small ions go to larger types by discrete changes of considerable magnitude.

(2) For all mobility-groups and ages (3 seconds to 140 seconds) investigated, the number of ions per unit mobility-group varies inversely as the density of atmospheric condensation-nuclei. Since ions are being produced at a constant rate, some other group outside the range studied must vary directly with nuclei-density.

(3) The shape of the mobility-spectrum is practically the same at a period of high nuclei-density as at low nuclei-density. Thus there is no preferential type of ion in this range which is removed by a condensation-nucleus to form a large or Langevin ion, and all types seem to be removed essentially at the same rate.

(4) The effect of age is to remove ions from the small-ion group and to add them to other groups, the ion probably growing in size by the addition of neutral aggregates, most likely water. The group in the range 0.94 to 0.47 cm/sec/volt/cm, discussed in connection with the work of Chapman, also grows at the expense of the small-ion group, thus showing that this group represents a definite stage in the development of an ion from the normal small ion to a large ion.

Size of the atmospheric ions

It is of interest to determine the size of the large ions which are formed by the combination of small ions and neutral condensation-nuclei. The well-known Langevin equation for the mobility of an ion is

$$k=0.815\ (e/M)(\lambda/C)\sqrt{(m+M)/m}$$

where k is the mobility of the ion, e is the electronic charge, λ is the mean free-path and m the mass of the ion, C is the root-mean-square speed and M the mass of the molecules of the gas through which the ion moves. This expression together with that for the mean free-path of a particle which is much larger than the molecules of the gas through which it moves

$$\lambda=(1/N\pi\sigma^2)$$

where N is the number of molecules per cubic centimeter and σ is the diameter of the moving ion, gives a diameter of 3.5×10^{-6} cm for ions having a mobility of 4.4×10^{-4} cm/sec/volt/cm. If the size be computed by Stokes law using Millikan's value for the mean free-path correction, an almost exactly similar result is found.

The size of the atmospheric condensation-nuclei which is measured in either an Aitken counter or a basically similar device is thus given by these experiments as greater than 3.5×10^{-6} cm in diameter. This

agrees with results obtained by other investigators. This result, however, does not preclude the existence of other types of nuclei, less hygroscopic, which may exist in the atmosphere, but which escape detection by this method.

In conclusion the writer wishes to express his thanks to Dr. Norris E. Bradbury, under whose direction this work was done, for his interest and his many valuable suggestions.

References

[1] O. W. Torreson and G. R. Wait, Terr. Mag., **39**, 47-64 (1934).
[2] J. Zeleny, Phil. Trans. R. Soc., A, **195**, 193-234 (1900).
[3] E. A. Yunker, Rev. Sci. Instr., **10**, 317 (1939).
[4] N. E. Bradbury and H. J. Meuron, Terr. Mag., **43**, 231-240 (1938).
[5] Seville Chapman, Phys. Rev., **52**, 184-190 (1937).

Stanford University,
Stanford University, California

ON THE CONTRIBUTION TO THE IONIZATION AT SEA-LEVEL PRODUCED BY THE NEUTRONS IN THE COSMIC RADIATION

By S. A. Korff

Since neutrons constitute a numerically important component of the cosmic radiation [see 1 of "References" at end of paper], the question arises as to the amount of ionization in the atmosphere at sea-level which they produce. This ionization will be produced in two ways: (*a*) By recoil-nuclei produced by the neutrons in collisions; and (*b*) by the ionizing radiation ejected from nuclei as a result of neutron-induced disintegrations. We may set limits to each of these contributions.

It is believed that most of the neutrons in the atmosphere at sea-level are evaporated out of nuclei by the high-energy cosmic radiation, and have initial energies of 10 to 30 Mev.* It has been pointed out by Bethe, Korff, and Placzek [2] that these neutrons will first be inelastically scattered by nitrogen nuclei. In this process, the neutron enters the nitrogen nucleus, causes the ejection of one or more nuclear particles, and usually emerges with about four Mev energy.** The bulk of the energy of the neutron is used in breaking up the binding of the nucleus, and hence is not transformed into ionization. The ionizing particles which are emitted will in general have energies which are small compared to the initial energy of the neutron, and it may be estimated [2] that of the order of five Mev per neutron will appear as ionization.

The measurements of the Montgomerys [3] show that at sea-level the rate of production of neutrons in air is $q=10^{-7}$ neutrons per cc per second. Hence the ionization produced by the process just described will be $q\times(5\times10^6)/32$ or 1.6×10^{-2} ions per cc per atmosphere per second.

The neutron, after inelastic collisions have slowed it down to below four Mev, will then lose energy by elastic collisions and will be slowed down until its energy is of the order of one volt or less. Hence the four Mev will appear as ionization, produced by the recoiling nuclei and again, multiplying this figure by the number of neutrons, we obtain 1.3×10^{-2} ions per cc per second as the contribution due to this process.

The slow neutrons will then be absorbed by the N^{14} (n,p)-reaction, giving rise to a proton of about one-cm range. This proton will produce $\sigma=10^4$ ions along its path. Therefore, the contribution to the total ionizations by these protons will be $q\sigma=10^{-3}$ ions per cc per sec. Hence we cannot account for more than 3×10^{-2} ions per cc per atmosphere per second of ionization produced at sea-level by neutrons in the atmosphere.

We must now consider whether any contribution arises from neutrons produced in the ground which might cause the ejection of radiation upward. We will assume that the Earth is composed of oxygen and silicon [4]. The rate of production q' of neutrons in these elements, per gram per second ($q'=qp$, where p is the density of air), will presumably be not substantially different from that in nitrogen. Neither neutrons, nor radiation induced by neutrons, can emerge from a depth of more than 20

*Some neutrons of much greater energy may exist, but there is no evidence for this, and they are probably numerically unimportant.

**This latter energy corresponds to the lowest excitation-level in the nitrogen nucleus.

or 30 cm, and hence we will consider only the production of neutrons in the top $1 = 20$ cm. This will then be $q'1 = 2 \times 10^{-3}$ neutrons per square-cm column per second. Neutrons in silicon can produce radiation which can emerge through such a column by the Si^{28} (n,γ)-reaction. The abundant isotope, Si^{28}, also has (n,p) and (n,α)-reactions, but the [illegible] Earth of such protons or alpha particles will be negligible and no contribution will arise from these. The gamma rays will, on the other hand, be able to pass upward for one or two hundred meters of air, and will have specific ionizations $s = 10$ ions per cm or less. In the most favorable case, all the neutrons will be captured by Si^{28}, and gamma rays will be emitted. If we suppose spherical symmetry in the gamma-ray emission process, then on the average one-half of the gamma rays will pass out into the air through the top hemisphere. Hence the flux i of gamma rays passing upward from the Earth's surface is, under the most favorable assumptions, 10^{-3} per cm^2 per second. Immediately above the Earth's surface, therefore, the gamma rays will produce $is = 10^{-2}$ ions per cc per second. This represents an upper limit for the radiation due to artificial radioactivity induced by cosmic-ray neutrons. Adding all the above amounts, the total ionization produced at sea-level due to all the effects produced by neutrons will not exceed 4×10^{-2} ions per cc per second. This is to be compared to the figure of about 1.5 ions produced by the ionizing cosmic radiation.

At higher elevations the neutrons are much more numerous and increase with elevation faster than the ionizing cosmic rays. At those levels the contribution will be proportionally greater than it is at sea-level, and can amount to about ten or fifteen per cent of the total effect produced by the charged particles.

Finally, the number of neutrons is roughly equal to that of the charged particles. Since each will most probably be eventually captured by nitrogen, nitrogen will be disintegrated, forming long-lived C^{14} at a rate of $q = 10^{-6}$ atoms per cc per second in the upper atmosphere. Hence the length of time before an appreciable fraction (one per cent) of a new isotope is formed is $(NP/q) \times 10^{-2}$, where N is the Lochschmidt number, and P is the pressure in atmospheres. In this case t is 10^{14} years, a period long compared to the supposed life of C^{14}. Similarly, in the oceans neutrons will be captured by hydrogen forming heavy water at roughly this same rate. Hence we must conclude that the neutrons in the cosmic radiation cannot be invoked as an explanation of the origin of certain isotopes in the Earth's crust, nor will they provide more than four per cent as much ionization at sea-level as the ionizing cosmic radiation produces.

The author is indebted to O. H. Gish for helpful discussions.

References

1. S. A. Korff, Rev. Mod. Phys., **11**, 211-219 (1939).
2. H. A. Bethe, S. A. Korff and G. Placzek, Phys. Rev., **57**, 573-587 (1940).
3. C. G. and D. D. Montgomery, Phys. Rev., **56**, 10-12 (1939).
4. Smithsonian Physical Tables. (The elements O and Si together comprise 74 per cent of the lithosphere. Consideration of the other elements will complicate the discussion, but will not substantially alter the result, except insofar as capture-processes in certain substances may reduce the number of neutrons available for the gamma-ray reactions mentioned.)

Bartol Research Foundation,
Franklin Institute,
Swarthmore, Pennsylvania

THE ELECTRICAL CHARACTERIZATION OF DAYS AT COLABA (BOMBAY, INDIA) DURING 1930-38

By S. M. Mukherji and A. R. Pillai

Systematic recording of atmospheric electric potential-gradient at Colaba commenced from the middle of June, 1930, with a photographic electrograph of the Cambridge Scientific Instrument Co.[1] The instrument was first installed in the old Milne Seismograph room of the Observatory but in February 1931 was transferred to a specially constructed hut in the open space near the sea-coast in the northeast corner of the Observatory compound.

A radium-spiral screwed to the outer end of an insulated metal rod which projects out horizontally through a hole in the western wall of the hut, is used as the collector. The spiral is placed 171 cm above the ground with its middle point 40 cm away from the outer surface of the wall during normal days. The distance of the collector from the wall is reduced suitably during disturbed weather.

The values of atmospheric electric potential-gradient at specified hours of the day are being published in the year book of the Observatory from 1930. In 1936 and 1937 the electrical character-figures of days and durations of negative potential were also given in addition to the hourly values of the potential-gradient. In the present note the electrical character-figures and duration of negative potential in hours for all the available days from 1930 to 1938 are given in a collected form.

In assigning the electrical character-figures to days the practice of the British Meteorological Office has been followed. This system has been recently discussed by Whipple.[2] In this method, "O" denotes absence of negative potential in a day, "1" implies the existence of negative potential at one or more times but with a total duration of less than three hours, while "2" indicates that the total duration of negative potential was for a period of three hours or more. At Colaba the day is reckoned from the local midnight (longitude 72° 49′ east).

In Table 1 are given the numbers of days of character-figures "0", "1", and "2", respectively, in each month of the year beginning from June 15, 1930, to end of 1938. Out of a total of 3122 days, character-figures could be assigned to 2758 days. The electrograms of the remaining 364 days were either lost due to the instrument being out of adjustment or could not be used due to failure of insulation. As the data for the year 1930 are incomplete and many days are missing in 1934 and 1935, these years were not considered in taking the monthly sums and means given in the Tables. Out of a total of 2192 days in 1931-33 and 1936-38, 2056 days are available for characterization. Of these, 1348 are "0"-days, 590 days are of character "1", and 118 of "2".

Total durations of negative potential of available days for the above period are given in Table 2.

[1] J. Sci. Instr., 5, 145-152 (1928).

[2] Terr. Mag., 42, 129-136 (1937).

TABLE 1—*Distribution of days according to electric character-figures*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Sum	Me
							"0"-Days—No negative potential-gradient							
1930	. .	. .	. .	. .	. .	0	7	12	13	13	22	26	93	1
1931	21	19	20	22	30	17	1	7	17	16	25	24	219	1
1932	31	23	21	25	26	11	6	9	14	15	25	21	227	1
1933	24	22	12	23	12	15	17	12	11	16	30	24	218	1
1934	23	25	16	28	28	8	10	0	3	28	28	24	221	2
1935	14	22	20	14	8	3	5	8	11	16	27	29	177	1
1936	18	25	15	18	28	9	10	15	11	26	20	24	219	1
1937	27	24	16	22	27	13	2	13	9	25	30	31	239	2
1938	24	23	24	20	22	7	7	10	14	21	26	28	226	1
Sum*	145	136	108	130	145	72	43	66	76	119	156	152	1348	11
Mean*	24	23	18	22	24	12	7	11	13	20	26	25	225	1
							"1"-Days—Negative potential-gradient < 3 hours							
1930	. .	. .	. .	. .	. .	11	21	15	7	5	3	3	65	
1931	8	9	7	7	1	8	18	21	7	6	4	1	97	
1932	0	3	5	3	4	12	18	13	13	11	3	4	89	
1933	5	6	13	6	17	14	10	10	13	14	0	6	114	
1934	3	3	7	1	3	14	15	2	4	2	1	1	56	
1935	6	4	6	4	0	3	9	1	3	3	2	1	42	
1936	5	3	8	4	3	13	16	13	16	5	5	4	95	
1937	2	1	9	8	2	12	21	13	14	4	0	0	86	
1938	7	3	7	6	6	14	22	19	15	6	3	1	109	
Sum*	27	25	49	34	33	73	105	89	78	46	15	16	590	5
Mean*	5	4	8	6	5	12	18	15	13	8	3	3	98	
							"2"-Days—Negative potential gradient ⋝ 3 hours							
1930	. .	. .	. .	. .	. .	6	0	1	8	1	0	0	16	
1931	0	0	0	1	0	4	12	2	2	5	1	0	27	
1932	0	0	0	0	1	5	5	1	3	4	0	1	20	
1933	2	0	4	1	0	1	3	5	3	0	0	1	20	
1934	5	0	5	1	0	8	3	0	0	1	1	0	24	
1935	2	1	2	0	0	0	1	0	1	0	0	0	7	
1936	1	0	2	0	0	6	0	0	3	0	1	1	14	
1937	0	0	1	0	0	3	6	0	6	0	0	0	16	
1938	0	1	0	0	3	9	0	2	1	4	1	0	21	
Sum*	3	1	7	2	4	28	26	10	18	13	3	3	118	1
Mean*	1	0	1	0	1	5	4	2	3	2	1	1	20	

*For 1931-33 and 1936-38 only.

The year at Bombay can be broadly divided into two seasons—dry and wet. November to April are the dry months; the wet season extends from the latter half of May to October. In the dry season, days are sunny with occasional high and medium clouds but with practically no rain. There may be about half a dozen occasions of rain and thunderstorm in this part of the year.

The principal cause of atmospheric-electrical disturbances contributing to "1"- and "2"-days in the dry months is the raising of dust

TABLE 2—*Total duration of negative potential-gradient in hours*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Sum	Mean
1930	...	...	...	...	...	46.0	7.3	6.3	66.6	10.0	0.3	2.9	139.4	1.7
1931	0.9	4.6	2.8	6.2	0.2	22.6	78.0	25.1	10.1	31.1	6.0	0.7	188.3	1.5
1932	0	1.0	4.9	1.8	6.2	38.0	41.2	13.2	21.5	31.6	1.9	9.7	171.0	1.6
1933	16.7	7.1	33.7	5.9	16.5	20.0	23.5	28.6	27.7	11.6	0	8.5	199.8	1.5
1934	24.2	0.9	29.4	5.8	0.3	50.9	24.8	0.8	4.5	3.9	7.1	0.1	152.7	1.9
1935	3.6	13.7	16.7	4.2	0	7.5	10.3	0.2	6.0	2.5	0.8	0.1	65.6	1.3
1936	4.6	1.0	15.1	2.9	1.4	36.0	4.7	10.5	24.8	2.6	8.1	6.5	118.2	1.1
1937	0.4	1.5	12.8	3.7	0.2	35.3	40.9	4.7	37.7	7.1	0	0	144.3	1.4
1938	2.3	5.7	4.1	2.1	14.1	60.4	21.6	24.9	20.5	22.1	8.5	0.1	186.4	1.4
Sum*	24.9	20.9	73.4	22.6	38.6	212.3	209.9	107.0	142.3	106.1	24.5	25.5	1008.4	84.0
Mean*	4.1	3.5	12.2	3.8	6.4	35.4	35.0	17.8	23.7	17.7	4.1	4.3	168.1	1.4

*For 1931-33 and 1936-38 only.

in the air. Dust-raising winds occur mainly in the afternoon, generally between 13^h and 20^h when the wind becomes gusty and blowing from about north-northwest, gains a speed exceeding 8 m/sec. After these conditions are established, the air becomes visibly charged with dust and the potential-gradient shows rather steep reversal. The duration of the negative potential varies from a fraction of an hour to a number of hours and the value of the potential-gradient, from a few to several hundred volts per meter, depending on the duration and strength of the gusty wind. Not less than 95 per cent of "1"- and "2"-days in the dry months are due to dust in the air. Tables 1 and 2 show that the frequency of dust-raising winds as indicated by days of character-figures "1" and "2" and duration of negative potential are greater in March than in other dry months. It has also been noticed that the potential-gradient drops down to a very low value with the incidence of sea-breeze. On a few occasions, the gradient even reverses sign and after a short while, attains its normal value. This is due to reasons other than dust in the air.

Rainfall at Colaba (yearly normal 70.5 inches) is chiefly confined to the monsoon months, June-September, and it rains almost every day. June and July are the months of heaviest rainfall. These features are exhibited in Tables 1 and 2. Thunderstorms occur generally during April, May, and October. Nearly 95 per cent of the days of character "1" and "2" are associated with rain. The rest are mostly due to thunderstorms without rain or with immeasurable rain and a few due to charged clouds.

Table 3 gives the normal rainy days in the monsoon months at Bombay and the average days of character "1" and "2" during 1931-33 and 1936-38. A rainy day is assumed as one in which 0.10 inch of rain or above has fallen. The agreement between rainy days and electrically disturbed days is striking. Of the "0"-days, there are about 20 in an average dry month and about ten in a monsoon month. Of the latter, about half of the number during 1931-33 and 1936-38 were associated with rain. Table 4 gives the total number of available "0"-days against specified amounts of rain in hundredths of an inch.

TABLE 3—*Rainfall and electrical characterizations "1" and "2" in monsoon months at Bombay*

Month	Normal No. rainy days	No. of days of character "1" and "2" during 1931-33 and 1936-38
June	15	17
July	23	22
August	20	17
September	14	14

TABLE 4—*Rainfall and electrical characterization "0" in monsoon months at Bombay*

Rain in hundredths of an inch	No. of "0"-days June-September, 1930-38
1– 5	85
6–10	30
11–15	17
16–20	10
21–30	10
31–63	4
	Total 156

Besides the above, there were also ten days of character "0" in October-November in the above period with rainfall varying between 0.01 and 0.63 inch. On the other hand, there were 13 days of character "1" and three days of character "2" during June-October, 1930-38, when there was no rain.

It has been found by examining a large number of individual cases of rainfall and the associated potential-gradients by one of us[3] that in about one-third of the cases the effect of rain on the potential-gradient was to lower the normal value but not to make it negative. There are a few occasions during pre- and post-monsoon days and during temporary breaks in monsoon when showers persistently raise the normal gradient. On a very few occasions some of the heavy showers have also increased the normal gradient considerably.

We are grateful to Dr. K. R. Ramanathan at whose suggestion the work was taken up and to Dr. S. R. Savur for kindly giving us all facilities to complete the work.

[3]A. R. Pillai, Proc. Ind. Sci. Congress (Lahore), 1939, 3, 17.

COLABA OBSERVATORY,
Bombay, December 18, 1939

THE ATMOSPHERIC POTENTIAL-GRADIENT AT POONA, INDIA

By J. M. Sil and K. S. Agarwala

In this paper the data for the potential-gradient at Poona collected on undisturbed days during September 1930 to December 1938 have been considered. The basis of these data is the continuous record of the Earth's electric field which was obtained here photographically. The undisturbed days at Poona are few and far between. A brief note on topography of the place and the general atmospheric conditions prevailing here is given below:

Poona is a hill station on a plateau formed on the chain of mountains, called the Western Ghats. Its height above mean sea-level is 1830 feet and its position is latitude 18° 30′ north, longitude 73° 53′ east. Here the monsoon season extends from June to September when the sky remains overcast with low clouds and it drizzles or rains occasionally; the two post-monsoon months (October and November) are sultry and calm; the winter (December to February) is marked with frequent mist or fog in the morning and haze in the evening while during the summer preceding the monsoon, wind is high and the atmosphere is laden with dust, and thundery weather prevails off and on in the afternoon.

The Earth's electric field was recorded continuously by a Cambridge electrograph which was provided with a "radium" collector, a Dolezalek electrometer, and a recording camera. The electrometer was kept in a closed chamber and the sulphur insulators of the supporting rod, carrying the collector, were placed inside a wooden box; the box and the chamber were continuously heated by electric lamps so as to maintain proper insulation. The "radium" collector was of the form of a helix and was exposed at a mean distance of 60 cm from the zero-potential surface. Arrangements were made to obtain automatically hourly time-marks at the bottom edge of the record, and at the beginning and end of every record the position of the zero-potential was marked by earthing the electrometer-needle for about a minute. The two zero-potential marks determined the position of the zero-line on the record. The paper-feed of the recorder was 14.7 mm per hour.

The apparatus was calibrated periodically once a fortnight in dry weather and more frequently in rainy season. The scale-value of the electrometer was maintained practically constant throughout. Periodical tests were also made for leak in the electrometer-system; the leakage in ten minutes did not ordinarily exceed ten per cent of the original value of the charge.

With numerous trees in the neighborhood the exposure of the collector was far from the ideal and in the absence of any other more suitable site in the observatory, simultaneous observations of the Earth's electric field were taken on "calm" days out in the open so that the

data obtained from the electrograph could be corrected for imperfect exposure. These control-observations were taken in an open field at a distance of about a mile from the observatory, following Simpson and Wright's method [see 1 of "References" at end of paper]. An ionium-collector, standardized by the Carnegie Institution of Washington, and an Ayrton-Mather electrostatic standard voltmeter were employed. In one hour, a set of 60 observations was taken at intervals of one minute, and in a day seven to eight such sets of readings were obtained. The data obtained from these control observations were compared with those derived from the electrogram for the corresponding period; the ratio of the two gave the "exposure-factor". Mean value of these factors was used to correct for the imperfect exposure of the electrograph.

For data given in this note, records pertaining to the least-disturbed days only were considered after a careful selection. During the period of eight years and four months, records of 416 days only were selected for the purpose. From these records the hourly values of potential-gradient were computed by evaluating the mean ordinates of the curve for the 60-minute intervals centered at the exact hours IST (Indian standard time). These values were reduced to volts per meter and then corrected by the "exposure-factor." The hourly values thus obtained have been utilized in the preparation of Table 1.

TABLE 1—*Values of potential-gradient, during undisturbed days in 1930-38, at Poona*
(Figures in parentheses indicate the number of days whose records form the basis of these data)

IST	Jan. (37)	Feb. (38)	Mar. (35)	Apr. (34)	May (34)	Jun. (34)	Jul. (30)	Aug. (36)	Sep. (41)	Oct. (30)	Nov. (33)	Dec. (34)
h												
00	79	74	69	57	57	53	55	57	63	63	71	83
01	74	67	66	55	53	54	54	55	63	57	65	76
02	65	58	59	50	53	53	57	55	58	57	59	65
03	56	52	52	44	51	52	55	55	56	54	55	60
04	57	55	48	42	49	53	58	53	60	54	55	58
05	62	58	51	52	52	56	64	62	68	61	63	66
06	76	66	60	62	63	64	75	62	75	69	81	87
07	90	82	73	78	77	78	86	76	82	80	97	100
08	111	93	87	79	72	67	69	75	78	90	105	126
09	115	105	94	85	71	65	64	72	75	103	115	133
10	134	118	92	70	68	63	61	70	73	96	108	133
11	121	97	85	62	63	61	61	61	67	77	87	125
12	86	76	58	54	57	60	61	59	64	69	72	92
13	73	57	48	53	55	59	59	58	61	65	68	71
14	53	55	48	51	53	58	55	56	60	63	60	66
15	52	51	46	49	51	55	54	55	59	57	60	58
16	52	50	43	47	49	52	59	55	57	54	57	56
17	50	49	45	46	50	48	48	50	51	54	59	66
18	65	56	51	54	53	51	50	49	59	65	69	77
19	78	71	57	57	60	51	51	51	64	72	75	98
20	88	89	68	70	67	53	52	51	64	77	83	105
21	87	85	71	72	68	56	55	52	67	73	79	108
22	87	83	71	62	60	56	53	59	67	59	77	99
23	85	78	71	61	58	55	55	57	64	63	79	93
Means	79	72	63	59	59	57	59	59	65	68	75	88

In Table 1 have been given hourly values of the atmospheric potential-gradient in volts per meter for each month of the year, together with the mean for the whole year. The number of selected days' records considered is shown in parentheses. Mean potential-gradient values for individual months have been obtained by taking one-twenty-fourth of the sum of each column and given in the last row of Table 1.

Examination of data in Table 1 would show that there is a diurnal as well as annual variation in the mean hourly value of potential-gradient. In general, the values are low during April to August but are high during December and January. The diurnal variation is almost of the same type throughout the year and during any one season this variation is very similar from month to month. According to seasons* prevailing at Poona, the hourly values of two or more months have therefore been grouped together and the average found for the number of months considered in the group. These hourly values for the different seasons together with the yearly average are given in Table 2.

TABLE 2—*Mean hourly values of potential-gradient at Poona, for different seasons and for whole year, based on data collected during 1930-38*

(Figures in parentheses indicate the number of days whose records form the basis of these data)

IST	Summer (Mar-May)	Monsoon (June-Sep.)	Autumn (Oct-Nov.)	Winter (Dec-Feb.)	Year	IST	Summer (Mar-May)	Monsoon (June-Sep.)	Autumn (Oct-Nov.)	Winter (Dec-Feb.)	Year
h						*h*					
	(103)	(141)	(63)	(109)	(416)		(103)	(141)	(63)	(109)	(416)
00	61	57	67	79	65	12	56	61	71	85	67
01	58	57	61	72	62	13	52	59	67	67	61
02	54	56	58	63	57	14	51	57	62	58	57
03	49	55	55	56	54	15	49	56	59	54	54
04	46	56	55	57	54	16	46	56	55	53	53
05	52	63	62	62	60	17	47	49	57	55	51
06	62	69	75	76	70	18	53	52	67	66	58
07	76	81	89	91	83	19	58	54	74	82	65
08	79	72	98	110	88	20	68	55	80	94	72
09	83	69	109	118	91	21	70	58	76	93	73
10	77	67	102	130	91	22	64	59	68	90	69
11	70	63	82	114	81	23	63	58	71	85	68

Curves in Figure 1 show the diurnal variation of the potential-gradient at each season of the year and the mean diurnal variation considering the whole year. It will be seen that the range of diurnal variation is the largest during the winter and the smallest during the monsoon season. The curve for the whole year shows characteristic features similar to those of the seasonal curves. During the day the maximum is reached at about 9^h or 10^h IST, then the potential-gradient goes on decreasing till the afternoon; there is a good rise again at night followed by a sagging in the early hours of the morning. Thus, there occur double maxima and double minima during the 24 hours. Ex-

*The seasons into which the months could be conveniently grouped for Poona are: (a) Summer—March, April, and May; (b) Monsoon—June, July, August, and September; (c) Autumn or post-monsoon period—October and November; (d) Winter—December, January, and February.

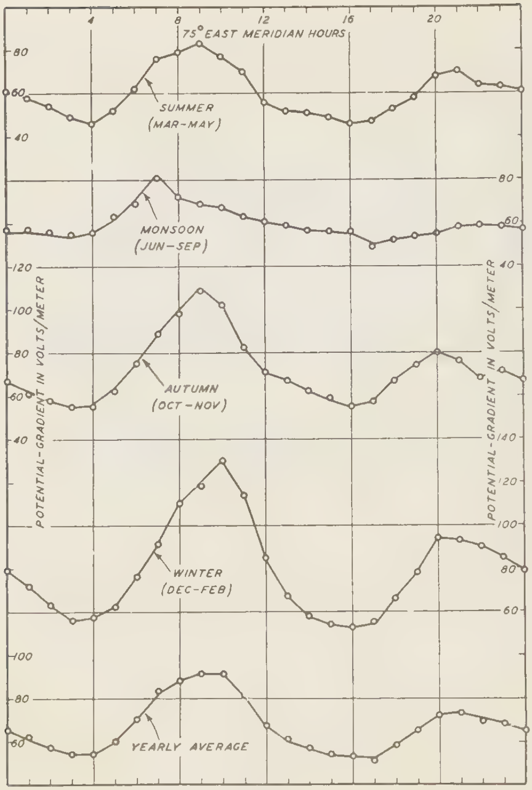


FIG. 1—DIURNAL VARIATION OF POTENTIAL-GRADIENT AT POONA

TABLE 3—*Results of Fourier analysis of the diurnal variation of potential-gradient at Poona (Lat. 18° 30′ N, Long. 73° 53′ E) during 1930-38*

Period	P_m	C_1	T_1	C_2	T_2	(C_2/C_1)
	v/m	%		%		
December to February (Winter)	79.6	14	08.48	35	03.24	2.50
March to May (Summer)	59.8	9	07.24	23	03.06	2.50
June to September (Monsoon)	60.0	13	07.42	8	02.36	0.61
October to November	71.7	14	09.18	24	03.00	1.71
Whole year	66.8	12	08.12	22	03.18	1.83

pressions for these curves have been found in the form of Fourier's series and the results of analysis have been given in Table 3.

Symbols used in Table 3 are as follows: P_m = the mean-of-day value of the potential-gradient in volts meter; C_1 and C_2 = the amplitudes of the 24-hour waves and 12-hour waves, respectively, expressed in percentage of P_m; T_1 = the Indian Standard Time corresponding to the maximum phase of the 24-hour wave; and T_2 = the Indian Standard Time corresponding to the phase of the first maximum of the 12-hour wave.

Fundamental wave—From Table 3 it would appear that the mean-of-day value of the potential-gradient varies from season to season—it is low in summer and monsoon months and is of the order of 60 volts/meter while in winter it attains the maximum of about 80 volts/meter. The amplitude of the 24-hour wave shows also similar variations with seasons—the amplitude is the largest in winter and is about twice the size of that in summer. The epoch of maximum of the 24-hour wave occurs generally in the forenoon, at about 08^h IST. The phase-angle of this vector which was counted from 00^h local midnight shows a slight variation in different seasons and it is found that the maximum of the 24-hour wave appears earlier in summer and later in autumn than the average time. The time-lag between the maximum phase in summer and autumn is about two hours.

The second harmonic—The 12-hour wave is quite prominent in the diurnal curve of potential-gradient at Poona. On the average its amplitude is about one-fifth of the mean-of-day value. The maxima of this wave appear in all the seasons at almost fixed hours, namely, at about $3^h\,00^m$ and $15^h\,00^m$ IST. Only during the monsoon months the ratio of the amplitudes of the 12-hour wave to 24-hour wave is less than one—in all other seasons this ratio is greater and shows the maximum value of 2.25 in summer and winter.

Other harmonics—The analysis of the yearly average curve for the diurnal variation of potential-gradient at Poona shows that the third and fourth harmonics are not conspicuous; their ratios to the mean-of-day value are respectively 3.6 per cent and 2.5 per cent only.

These results although comparing favorably with those [2, 3] obtained at other land-stations in India, do not fall in line with the results derived from the excellent data collected over the oceans [4]. The large factor of (C_2/C_1) would indicate that the diurnal curve of potential-gradient at this land-station is highly distorted. As the records relate to so-called "undisturbed" days only, it would appear that in these "undisturbed" days, although prominent meteorological phenomena were absent, certain elements of local weather were affecting the Earth's electrical field directly or indirectly. Examination of the pressure- and temperature-data of the place fails however to show any direct or satisfactory relation to the potential-gradient data.

Annual variation of potential-gradient at Poona—The mean-of-day values given in the last row of Table 1 have been plotted in Figure 2 to show the annual variation of potential-gradient at Poona.

The curve displays a single maximum and a single minimum coming in December and June, respectively. During April to August, the potential-gradient values are generally low. A gradual rise takes place as the winter is approached but towards the end of winter the potential-

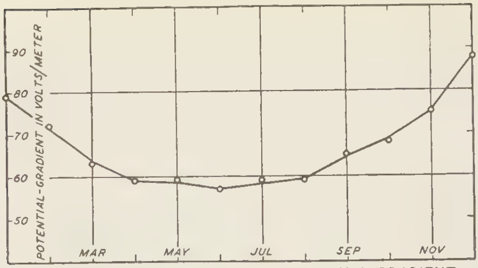


FIG. 2—ANNUAL VARIATION OF POTENTIAL-GRADIENT AT POONA

gradient begins to decrease. The mean value for the year is 67 volts per meter; the maximum and the minimum values during the year are 162 per cent and 85 per cent, respectively, of the yearly mean.

This curve of potential-gradient based on the data for all hours is similar to one prepared with the help of the data for $10^h\ 00^m$ IST only and given together with the curves obtained at Poona of conductivity, dust-, ion-, and nuclei-content of the air as Figure 1 in a previous note [5]. In relation to these elements characteristics of the annual variation of potential-gradient had been discussed there.

Our thanks are due to the Director-General of Observatories, Poona, for providing us facilities for carrying out this work.

References

[1] G. C. Simpson and C. S. Wright, Proc. R. Soc., A. **85**, 175-199 (1911).
[2] A. V. R. Telang, Indian J. Phys., **5**, 755-767 (1930).
[3] G. C. Simpson, Mem. Indian Met. Dept., **21**, Pt. 6 (1913).
[4] S. J. Mauchly, Terr. Mag., **28**, 61-81 (1923).
[5] J. M. Sil, Terr. Mag., **43**, 139-142 (1938).

Meteorological Office,
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A SIGNIFICANCE-TEST FOR ELLIPTICITY IN THE HARMONIC DIAL

By John W. Mauchly

(1) *Introduction*—The Fourier coefficients obtained from harmonic analysis of observations of periodic or quasi-periodic phenomena may be conveniently exhibited as points in Euclidean space. As a simple illustration, the 12-hour oscillations in barometric pressure, which have occurred at any one station on N different days, may be represented both in amplitude and in phase by N points in a plane. This device has been used by Bartels [see 1 and 3 of "References" at end of paper], Chapman (who gave it the name "harmonic dial"), and others, in studying atmospheric tides, magnetic variations, and similar phenomena. As an example, Figure 1 by Bartels is here reproduced [1].

FIG. 1—HARMONIC DIALS FOR 24-HOUR, 12-HOUR, 8-HOUR, AND 6-HOUR SINE-WAVES, DIURNAL VARIATIONS EASTERLY DECLINATION, HUANCAYO OBSERVATORY ON 103 SINGLE VERY QUIET DAYS IN SOUTHERN SUMMER—AFTER BARTELS
(EACH DOT MARKS ONE DAY; LENGTH OF VECTOR FROM CENTER GIVES AMPLITUDE, AND ITS DIRECTION—AS READ FROM DIAL—GIVES LOCAL MEAN TIME OF FIRST MAXIMUM OF SINE-WAVE; PROBABLE-ERROR ELLIPSES)

In the case of a strictly persistent periodicity (amplitude and phase both constant) affected only by random errors, the "cloud" of points in the harmonic dial tends toward a symmetrical distribution, and one may characterize the error-variance by a single number and draw a probable-error *circle* about the centroid of the points. However, cases arise in which the cloud is considerably elongated, and the probable-error circle should be replaced by an *ellipse*. Obviously, borderline

cases also arise, in which it is doubtful whether the degree of ellipticity displayed by the sample is to be ascribed to ellipticity in the parent population or merely to sampling deviations from a "circular" parent population.

The problem of testing the significance of the ellipticity of a given sample is put as follows: What is the probability of obtaining, from a circular normal population, a random sample of N points for which the ellipticity is as great or greater than that actually obtained in the given sample of N points? A statistic L_e will now be found as an appropriate measure of ellipticity and its distribution will be obtained, leading to a very simple significance-test. The material presented by Bartels [1, 3] will then be used to illustrate the application of this test. At the end of the paper will be found a few remarks on extensions and generalizations.

(2) *The ellipticity statistic,* L_e—Let us designate the observed variables as x and y, and calculate s_x^2, s_y^2, and r, which are, respectively, the variance of x, the variance of y, and the coefficient of correlation between x and y, for the sample of N. Let the two roots of the characteristic equation

$$\phi(k) \equiv \begin{vmatrix} s_x^2 - k & s_x s_y r \\ s_x s_y r & s_y^2 - k \end{vmatrix} = 0 \qquad (1)$$

be k_1 and k_2 ($k_1 > k_2$). These roots are invariant under rotation of the coordinate axes, and are in fact the variances, s_1^2 and s_2^2, found when the first coordinate axis lies along the major axis of the "probable-error ellipse" for the sample cloud, and the second coordinate axis lies along the minor axis of that ellipse. (The major and minor semi-axes of this ellipse are equal to 0.833 s_1 and 0.833 s_2.)

Now any function of s_1/s_2 might be used to describe the ellipticity of the sample, but the symmetrical function,

$$L_e \equiv 2s_1s_2/(s_1^2+s_2^2) = 2(k_1k_2)^{1/2}/(k_1+k_2) = 2s_xs_y(1-r^2)^{1/2}/(s_x^2+s_y^2) \quad (2)$$

seems most appropriate (see section 6).

(3) *The distribution of* L_e—The distribution of L_e may be obtained from the joint distribution of k_1 and k_2. Girshick [2] has found that, for two variates with zero mean in the sample, drawn from a normal bivariate population of unit-variance, the joint distribution of k_1 and k_2 is given by

$$(1/4(N-3)!)\ (k_1-k_2)(k_1k_2)^{(N-4)/2}\ e^{-(k_1+k_2)/2}\ \mathrm{d}k_1\mathrm{d}k_2 \qquad (3)$$

Put

$$u = 2(k_1k_2)^{1/2}/(k_1+k_2) \qquad v = k_1+k_2 \qquad (4)$$

The Jacobian of this transformation is

$$uv/2(1-u^2)^{1/2} \qquad (5)$$

After carrying out the transformation, we find that u and v are independently distributed according to the product-function

$$D(u)D(v) = [(N-2)u^{N-3}\mathrm{d}u]\{[1/(N-2)!](v/2)^{N-2}e^{-v/2}\mathrm{d}(v/2)\} \qquad (6)$$

The factor involving v is seen to be nothing more than the chi-square distribution-function for $(2N-2)$ degrees of freedom. Since u is the ellipticity-statistic, L_e, we have the distribution, on the assumption of a circular parent population

$$D(L_e) = (N-2)L_e^{N-3}\ \mathrm{d}L_e \tag{7}$$

(4) *Significance-tests based on L_e* — Suppose that from a given sample of N points in a plane, there is obtained a numerical value for L_e. The probability that a value as small or smaller than this might be obtained in a random sample of N points from a circular population will be indicated by the notation $P(L_e)$ and is easily found to be

$$P(L_e) = (N-2)\int_0^{Le} u^{N-3}\ \mathrm{d}u = L_e^{N-2} \tag{8}$$

When $P(L_e)$ is close to unity, or at least not very small, one is inclined to accept the hypothesis that the population from which the actual sample was drawn was circular, but when $P(L_e)$ is quite small, we may prefer to reject this hypothesis and accept the alternative hypothesis that the parent population was elliptical.

In some cases it may be desirable to comprehend, in a single significance-test, the evidence furnished by several two-dimensional clouds which cannot be directly combined. If there are just two clouds, one of M points and one of N points, with $M \neq N$, then the *product* L, of the separate statistics, L_{eM} and L_{eN} has the distribution

$$D(L_{eM}L_{eN}) = D(L) = [(N-2)(M-2)/(M-N)]L^{N-3}(1-L^{M-N}) \quad (M \neq N) \tag{9}$$

and integration yields the significance-test function

$$P(L_{eM}L_{eN}) = P(L) = [1/(M-N)][(M-2)L^{N-2} - (N-2)L^{M-2}] \quad (M \neq N) \tag{10}$$

When $M = N$, these equations become

$$D(L_{eN}L_{eN}) = D(L) = -(N-2)^2 L^{N-3} \ln L \mathrm{d}L \tag{11}$$

$$P(L_{eN}L_{eN}) = P(L) = L^{N-2}[1-(N-2)\ln L] \tag{12}$$

In these equations, $\ln L$ is the natural logarithm of L.

(5) *Application to harmonic analysis—examples* - Each of the four harmonic dials in Figure 1 contains 103 points, illustrating, respectively, the 24-hour, 12-hour, 8-hour, and 6-hour Fourier coefficients for 103 days. The probable-error ellipse for the 24-hour wave is far from circular, the others are not so extreme. From the ratio of major to minor axis which Bartels [1] has tabulated, L_e for each case may be calculated. On the assumption that the 103 points are truly random samples, we may calculate $P(L_e)$, and Table 1 gives these values. Actually, in some cases these points are for adjacent days, and are not independent; however, no account will be taken of that feature in this example

Table 1

Harmonic	Ratio of axes	L_e	$P(L_e)$
24-hour	1.63	0.8915	10^{-5}
12-hour	1.13	0.9926	0.47
8-hour	1.21	0.9781	0.10+
6-hour	1.24	0.9773	0.10−

Here the significance-tests merely confirm the judgment of Bartels, who considered only the 24-hour wave as significantly elliptical in distribution. But consider a case in which the axis-ratio for the ellipse is "moderate"—say, 1.40. If N is only 40, $P(L_e)$ is about 1/10, but if this ratio is found from a cloud of 170 points, $P(L_e)$ is then near 10^{-4}. An example close to this has been supplied by Bartels [3], namely: The horizontal magnetic intensity at Sitka, for 151 different days in May, June, and July, during sunspot-maximum years, yields a 24-hour harmonic dial with a cloud of axis-ratio 1.46. L_e is then found to be 0.9324, and $P(L_e)$ is 3×10^{-5}.

As an example of the application of equation (12), one *might* set out to test the 8-hour and 6-hour waves of Table 1 together. The $P(L)$ calculated from (12) is 0.06, smaller than either of the probabilities in Table 1, but larger than their product, 0.01. Use of equation (12) is *not* proper in this instance, however, for the points in the two dials are not independent of each other. It should also be noted that these tests, like most others, take no account of the conscious selection which the user often exercises in choosing one or two extreme cases from a larger number of less striking figures.

(6) *Extensions and generalizations*—The ellipticity-statistic, L_e, as defined in this paper for two dimensions, is a special case of the statistic suitable for n dimensions

$$L_S = |s_{ij}|^{1/2}/S_0^{n/2} \tag{13}$$

where $|s_{ij}|$ is the determinant of the variances and covariances of the n-dimensional sample, and S_0 is the arithmetic mean of the n sample variances. The author shows elsewhere [4] that this is a power of the Neyman-Pearson likelihood-ratio criterion [5] for testing the hypothesis of "*sphericity*". Significance-tests and other matters pertaining to the n-dimensional case will be found in reference [4].

A further problem is that of finding the distribution of this statistic when the hypothesis of "sphericity" is not true.

References

[1] J. Bartels, Terr. Mag., **37**, 291-302 (1932).
[2] M. A. Girshick, Ann. Math. Stat., **10**, 203 (1939).
[3] J. Bartels, Trans. Amer. Geophys. Union, 129-131 (1931).
[4] J. W. Mauchly, Ann. Math. Stat., **11**, in press (1940).
[5] J. Neyman and E. S. Pearson, Phil. Trans. R. Soc., A, **231**, 289-337 (1933).

Ursinus College,
Collegeville, Pennsylvania

ELECTRODYNAMIC HYDROLOGY

By H. Löwy

From the electric point of view the soil constitutes a mixture of dielectric and conductive substances. The substance of the rock and the air, contained in its pores, represent the dielectric part of the rock; the water and metallic ores the conductive part. In saturated rocks the water fills continuously the pores. This is the case in humid regions. In the deserts, on the contrary, the water, in general, is dispersed in the rocks. To this difference corresponds the difference of electric prospecting methods: The resistivity method of Gish, Rooney, and Wenner being applicable in humid regions; the electrodynamic method being applicable in the desert. The desert-soil, under normal conditions, represents a conductive suspension. I have indicated [see 4 of "References" at end of paper] the general equations which describe the dielectric phenomena of conductive suspensions. These equations reduce, as I have shown [7], to equations (1) and (2).

$$[\bar{\epsilon}] = V_w + [\epsilon_c]\, v_c \tag{1}$$

$$v_a + v_c + V_w = 1 \tag{2}$$

$\bar{\epsilon}$ and ϵ_c signify the dielectric constants of the soil and the soil-substance. v_a and v_c are the volumes (contained in 1 cc of the soil) of the air and of that part of the soil-particles which are not covered with water-films. $[x]$ is an abbreviation for $(x-1)\ (x+2)$. V_w signifies the electrodynamic volume of the water in 1 cc of the soil. The definition of this notion I have given elsewhere [4]. Here I will only say that the electrodynamic volume is proportional to the electric moment of the soil, being situated in an electric field of intensity 1. I have called this quantity "electrodynamic volume" because it has the dimension of a volume and, in certain cases, has the same value as the geometrical volume of the conductive particles. In the case that water covers the soil-particles in form of films, *the electrodynamic volume is equal to the geometrical volume, enveloped by the exterior surface of the films.*

(1) and (2) are the *fundamental equations of electrodynamic hydrology.* In the following I discuss some applications of these equations.

(I) *Electric measurement of water-content*

In absence of free water, the water-content of the soil is equal to the volume v_f of the films (in 1 cc). Since all quantities in equation (1) are positive and $v_f < V_w$, we obtain $v_f < [\bar{\epsilon}]$. The water-content is smaller than $[\bar{\epsilon}]$.

If the water covers all soil-particles in form of films, $v_c = 0$ and equations (1) and (2) reduce to

$$[\bar{\epsilon}] = V_w \tag{3}$$

$$v_a + V_w = 1 \tag{4}$$

If p is the porosity, $(1-p)$ signifies the volume of the soil-particles in 1 cc. The particles being all covered with films, the volume v_f of these films (in 1 cc) is, therefore, equal to the difference of the electrodynamic volume V_w and the volume $(1-p)$.

$$v_f = V_w + p - 1 \tag{5}$$

The knowledge of the electrodynamic volume of the soil and its porosity enables one to determine the water-content of the soil.

The measurement of V_w reduces, according to (3), to the measurement of the dielectric constant of the soil. This measurement can be made from the surface of the soil, without disturbing its structure. It has an advantage over the usual methods which utilize samples.

From the volume v_f of the films one can, as I have shown [7], deduce their thickness. The *electric measurement of film-thickness* differs essentially from the methods used by Lord Rayleigh [2] and Langmuir [3]. Electrically one does not measure the thickness of a single film, but of a great many films, dispersed in the space. This case which often occurs in nature, for instance in colloidal solutions, is not accessible to the usual methods.

(II) *A problem of plant biology*

In March 1939, in the Libyan Desert, I used formula (5) for measuring the water-content of the soil after a slight rain which had fallen on March 6. Measurements made one day later, on March 7, gave $v_f = 0.023$, that is, a water-content of 2.3 per cent. On the following day, March 8, the measurement of ϵ gave a negative value of the film-volume. This shows that, during the 24 hours between the two measurements, the drying of the soil had made such progress that the films had reduced to a small layer of "solidified" water [14]. The water in this layer had lost its conductivity under the action of the adsorptive forces. When this stage of dryness is reached, that is, when

$$V_w < (1-p) \tag{6}$$

one must replace the hydrologic equations (1) and (2) by the equations of dielectric mixtures of H. A. Lorentz [1]. I have shown how one can deduce from these equations the thickness and volume of the "solidified" layers [8].

The electric discontinuity, indicated by relation (6), and occurring during the drying of the soil, has a counterpart in a discontinuity of other physical properties, which appears when plants, for want of water, begin to wilt.

We read in a paper of G. J. Bouyoucos [11] on this subject: "The data, as reported by Parker and by Veihmeyer and Edlefsen show that in the narrow range around the wilting-point a pronounced change occurs in the relationship between the soils and their moisture-content, regardless of whether this change is measured by vapour-pressure, freezing-point depression, rate of evaporation, surface-forces, or energy-changes." Bouyoucos adds: "The change in the curves must simply mean that the free water has ceased to operate and that the thin, discontinuous moisture-films have come into play" [11].

One must distinguish between the facts related by Bouyoucos, and the hypothesis he makes for explaining these facts. According to that hypothesis, the discontinuity appears, when the free water (that is the gravitational and capillary water) has evaporated and only the films remain. The electric discontinuity, on the contrary, appears in a more advanced stage of drying. It is probable that all discontinuities correspond to the same state of the soil and that, therefore, the desert plants utilize also the non-solidified part of the films.

If v_s signifies the volume of the solidified layers (in 1 cc), and v_u represents the available part of the films, then

$$v_u = v_f - v_s \tag{7}$$

In order to test this view, it would be necessary to combine measurements of the dielectric constant of the soil with botanical observations of the wilting-point.

In year-book No. 36 of the Carnegie Institution [12], in the report on plant biology, H. A. Spoehr has emphasized the practical value of systematic measurements of soil-humidity and of the work done in this respect by the Desert Laboratory of the Institution.

Using the electrical method, one could, without disturbing the structure of the soil, extend the range of the measurements beyond the limit of the solidified water [8].

(III) *Geologic structure*

In the winter of 1938-39 I measured in the Libyan Desert at many places and in different depths, the dielectric constant $\bar{\epsilon}$ of the soil. I have observed that one can trace $[\bar{\epsilon}]$-constant lines, which extend over great distances without touching or intersecting. *These lines, therefore, reveal a structure of the soil.* Equation (1) shows what kind of "structure" it is. According to this equation, the dielectric constant $\bar{\epsilon}$ depends on the hydrologic (V_w) and the petrographic properties (ϵ_c, v_c) of the soil.

In small depths, all soil-particles are normally covered by water-films and equation (1) reduces to (3). The "iso-dielectric lines" are, in this case, lines of equal electrodynamic volume and reveal, what I call, the hydrologic structure. I have given elsewhere [6] some examples of this structure. In the boring logs this structure is totally effaced by the water used in the boring procedure.

In great depths, the water-content is negligible (V_u-0), and the iso-dielectric lines reveal the petrographic structure of the sub-soil. Since the difference between the dielectric constants of the old and more recent formations are greater than the analogous speed difference of the seismic waves, one is led to hope that the iso-dielectric method will prove to be useful for the structural analysis of great depths.

(IV) *Electric classification of rocks*

Another geologic application of equations (1) and (2), is as follows:

Designating by $\bar{d}$ the density of the rock, with d_c the density of the substance of this rock, we obtain in case the rock is dry ($V_w = 0$), from equation (1) the relation

$$[\epsilon_c] = (d_c/\bar{d})\ [\bar{\epsilon}] \tag{8}$$

With this formula, one can deduce the dielectric constant of the rock-substance from the dielectric constant of the rock [10]. A systematic study of the different rocks with the aid of formula (8) would be of great importance. The knowledge of the dielectric constants of the different rock-substances enables one to identify, from the surface, the different sorts of rock. Designating with ϵ'_c the minimum, with ϵ''_c the maximum of ϵ_c, that is, $\epsilon'_c \leq \epsilon_c \leq \epsilon''_c$, we deduce from equation (1) that:

(1) $\bar{\epsilon} < \epsilon'_c$ indicates the presence of sediments (non-consolidated rocks).
(2) $\epsilon'_c \leq \bar{\epsilon} \leq \epsilon''_c$ indicates the presence of igneous rocks (consolidated rocks).
(3) $\bar{\epsilon} > \epsilon''_c$ indicates the presence of ground-water and ores. The demonstration is given in [5].

The constant ϵ_c represents the limit to which all consolidation-processes in the interior of the Earth tend. According to the observations of H. F. Reid [15] it is probable that such processes preceded the great Californian earthquake in April 1906. I suggest the mak ng of systematic observations of the time-variations of the electric soil-constants with a view to ascertain the activity of faults [5].

(V) *Soil-mechanics*

The knowledge of the constant ϵ_c is also important for the problem of foundations. The settlement of a clay-layer under the load p of a building is caused, according to the theory of Terzaghi [13] by the diminution of the water, contained in the pores of the clay. At first, especially in the humid regions, the soil is saturated with water. Under the increasing load of the building the moment arrives when the water no longer continuously fills the pores of the clay. The soil approaches the state where equations (1) and (2) become valid. Putting $v_a = 0$, we obtain the compressibility as in equation (9)

$$\triangle V_w / \triangle p = \{1/(1-[\epsilon_c])\}\ (\triangle[\bar{\epsilon}]/\triangle p) \tag{9}$$

and the consolidation as in equation (10)

$$1 - V_w = (1-[\bar{\epsilon}])/(1-[\epsilon_c]) \tag{10}$$

Until now, these quantities have been measured in the laboratory with the oedometer, using soil-samples. With the electric method one can measure the compressibility and consolidation of the soil on the building-lot and from the surface without disturbing the structure of the soil.

It will be possible, in this way, to study more intimately the hydrologic conditions of the soil at the critical value of the load, when the "elastic" settlement is followed by plastic flow. This mechanical discontinuity is probably also a counterpart of the electric discontinuity on the limit between the solidified and the non-solidified state of the films. From the mechanical point of view, the electric discontinuity probably marks the limit of the elastic deformations of the soil.

(VI) *Infiltration of rain*

Designating with h_r the height of the rain-column and supposing that the whole quantity of rain infiltrates in the soil, the infiltration-depth H is given by

$$H = h_r / \triangle[\bar{\epsilon}] \tag{11}$$

$\triangle [\bar{\epsilon}]$ signifies the difference of the values of $[\bar{\epsilon}]$ after and before the rain.

If the evaporation and the superficial discharge cannot be neglected, one must replace h_r by $h'_r < h_r$, where h'_r signifies the height corresponding to the infiltrated part of the rain. The demonstration of formula (11) is given in [6].

(VII) *Prospecting for ores*

In case conducting ores are present in the soil, one must replace the electrodynamic volume V_w of the water by V, where

$$V = V_w + V_m \tag{12}$$

the sum of the electrodynamic volume of the water and that of the metallic ores. One can then utilize equation (1) for the electric determination of the ore-content of rocks [9, 10].

(VIII) *Electrodynamic hydrology and chemistry*

In the preface of the book of F. W. Smith "The effect of moisture on chemical and physical changes" (1929), F. G. Donnan writes: "There is perhaps no more interesting and at the same time more puzzling group of phenomena than the chemical and physical effects produced by minute traces of water. It has been known for a long time that small quantities of water exercise a most important catalytic effect on the velocity of many chemical reactions, whilst the very interesting researches of Professor H. B. Baker and Professor A. Smits have drawn attention to the remarkable phenomena which appear when liquids and solids are subjected to a process of very intensive drying."

With respect to the problems, emphasized by Donnan, I will evaluate the minimum quantity of water which can be measured with my method. As an example, the gas reaction in a mixture of different gases in which water-drops are dispersed, will be considered.

Designating with the index c the gas mixture, including any air that may be present, we can put $v_n = 0$, and equations (1) and (2) become equation (13).

$$[\bar{\epsilon}] = V_w + (1 - V_w)\,[\epsilon_c] \tag{13}$$

The sensitivity of the method is given by equation (14)

$$\triangle V_w / \triangle \bar{\epsilon} = \{1/(1 - [\epsilon_c])\}\ \{3/(\bar{\epsilon} + 2)^2\} \tag{14}$$

For gases $\epsilon_c = 1$. Supposing the water-content at first zero, that is $\bar{\epsilon} = \epsilon_c$, we obtain for the variation $\triangle V_w$, that is, the minimum water-quantity which can be measured

$$\triangle V_w = \triangle \bar{\epsilon} / 3$$

Utilizing a condenser of the capacity $C_0 = 10$ cm and an instrument with which one can measure capacity-variations $\triangle C = 10^{-4}$ cm, we obtain

$$\triangle \bar{\epsilon} = \triangle C / C_0 = 10^{-5}$$

The corresponding variation of V_w is

$$\triangle V_w = (10^{-5}/3) \text{ cc}$$

If the gas mixture is introduced into a condenser, one could measure such small quantities of water-content during the reaction.

References

[1] H. A. Lorentz, Theory of electrons (1909).
[2] Lord Rayleigh, Proc. R. Soc., A, **47**, 364-367 (1890).
[3] I. Langmuir, Proc. R. Soc., A, **170**, 1-39 (1939).
[4] H. Löwy, Phil. Mag., **26**, 453-457 (1938).
[5] H. Löwy, Phil. Mag., **27**, 576-578 (1939).
[6] H. Löwy, Phil. Mag., in press.
[7] H. Löwy, Phil. Mag., in press.
[8] H. Löwy, Phil. Mag., in press.
[9] H. Löwy, Physik. Zs., **35**, 745-746 (1934).
[10] H. Löwy and M. M. Ghali, Beitr. Geophysik, **52**, 334-343 (1938).
[11] G. J. Bouyoucos, Soil Science, **45** (1938).
[12] Carnegie Inst., Year Book 36, 197-199 (1937).
[13] K. von Terzaghi und O. K. Fröhlich, Theorie der Setzung von Tonschichten, Leipzig und Wien (1936).
[14] C. A. Hogentogler, Engineering properties of soil, New York, McGraw-Hill Book Co. (1937).
[15] Reid, H. F. The mechanics of earthquakes. The California earthquake of April 18, 1906. Report of State Earthquake Commission, **2** (1910).
[16] J. H. Smith. The effect of moisture in chemical and physical changes, London (1929).

Cairo, Egypt, November 19, 1939

THE IONOSPHERE AT HUANCAYO, PERU, OCTOBER TO DECEMBER, 1939

By H. W. Wells and R. C. Coile

This report on ionospheric conditions is in continuation of those published in preceding issues of this Journal[1] submitting results of continuous multifrequency ionospheric recordings at the Huancayo Magnetic Observatory, Department of Terrestrial Magnetism, Carnegie Institution of Washington. The current data for October, November, and December, 1939, are obtained from recording for each hour of the day and for every day of the month except for short intervals necessary for maintenance of the equipment. This multifrequency apparatus sweeps through a frequency-range from 16.0 to 0.516 mc/sec every 15 minutes.

Table 1 contains mean hourly values of virtual height, critical frequency, and lowest frequency received for the fourth quarter of 1939. Figure 1 presents the data of Table 1 in graphical form. The following general discussion of characteristics is pertinent.

(1) *F-region*—Virtual heights during the daylight hours were nearly the same for October and November, but generally greater for December, showing a characteristic similar to the same quarter of 1938. The maximum heights for each month were recorded during the post-sunset "hump." The maximum heights for October and November were about the same, with slightly lower values in December. The phenomenon observed in 1938 that the maximum heights occurred at approximately 19^h, 20^h, and 21^h for October, November, and December, respectively, was repeated in 1939.

The maximum critical frequencies showed a decreasing trend for the three months, with the time of maximum being approximately 09^h, 10^h, and 15^h, respectively, contrary to the results of 1938, when the time of maximum critical frequency was at 09^h for each of the same three months. In November 1939, as in November 1938, the graph shows ionization decreasing fairly evenly from the morning maximum through about 18^h in contrast to the more characteristic midday dips shown in the curves for October and December.

(2) *F_1-region*—Virtual heights for the three months showed a decreasing characteristic in contrast to the upward trend of the previous quarter. Maximum F_1-region critical frequencies were consistently recorded around noon. The maximum values show a small decreasing trend for this quarter.

(3) *E-region* Since July, 1939, tabulations of E-region virtual heights have been discontinued because of the absence of significant variations or trends. The E-region critical frequencies for this quarter exhibited a small decreasing characteristic.

[1]Terr. Mag., **43**, 169-171, 257-260, and 467-470 (1938); **44**, 85-88, 195-198, 321-325, and 395-399 (1939); **45**, 49-52 (1940).

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory,* October to December, 1939

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
	October, 1939							November, 1939							December, 1939						
h	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec
00			244			9.83				294			8.14				340			7.04	
01			252			8.51				272			7.77				326			6.52	
02			260			7.57				267			7.39				317			5.94	
03			271			6.90				253			6.47				308			5.84	
04			277			6.15				247			5.65				291			5.33	
05			269	0.88		5.40	0.79			266	0.88		5.36	0.84			273	0.98		5.11	0.69
06			267	2.16		8.57	1.35			255	2.32		8.33	1.04			256	2.09		7.56	0.76
07		245	254	2.93	4.75	11.54	1.74		240	242	2.91	4.55	10.77	1.35		233	243	2.72	4.80	9.71	0.98
08		240	279	3.54	5.07	13.15	2.02		232	275	3.42	4.97	12.08	1.82		229	291	3.31	5.02	11.04	1.13
09		233	285	3.83	5.27	13.57	2.19		225	289	3.73	5.19	12.71	2.10		223	306	3.63	5.13	11.66	1 32
10		225	293	4.08	5.38	13.13	2.27		221	294	3.93	5.33	12.77	2.17		217	326	3.81	5.31	11.80	1.48
11		221	299	4.20	5.48	12.49	2.26		218	307	4.03	5.45	12.59	2.20		214	337	3.94	5.41	11.49	1.57
12		217	304	4.16	5.51	12.10	2.38		215	305	4.07	5.47	12.50	2.26		213	340	3.98	5.41	11.34	1.65
13		213	299	4.12	5.41	11.73	2.32		215	306	3.97	5.37	12.40	2.23		214	339	3.93	5.35	11.53	1.66
14		219	291	3.96	5.25	11.69	2.31		216	296	3.77	5.13	12.40	2.12		216	324	3.75	5.19	11.81	1.65
15		225	288	3.63	4.98	11.80	2.10		214	282	3.48	4.75	12.33	1.95		213	299	3.43	4.86	11.92	1.39
16		247	277	3 16	4.53	11.98	1.65		233	277	2.97	4.35	12.19	1.46		219	284	2.94	4.46	11.79	1.07
17			271	2.49		12.12	1.25			261	2.40		11.79	1.04			249	2.53		11.70	0.87
18			310	1.39		11.94	1.18			292	1.41		11.18	1.23			276	1.72		11.40	0.94
19			392	0.96		11.01	0.92			358	0.93		10.24	0.90			305	0.85		11.01	0.72
20			376			10.51				380			9.31				329			9.66	
21			329			10.34				376			8.78				362			8.67	
22			289			10.43				351			8.47				355			8.00	
23			259			10.27				324			8.43				351			7.41	

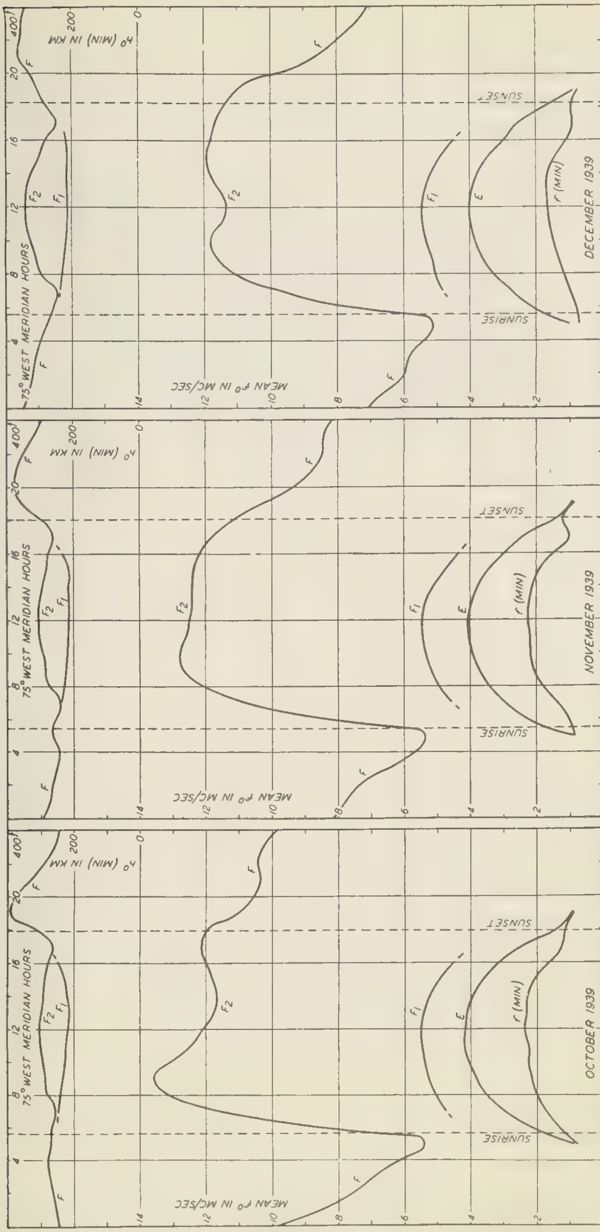


FIG 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, OCTOBER, NOVEMBER, AND DECEMBER, 1939, HUANCAYO, PERU

(4) *Lowest frequency received*—The lowest frequency recorded during the sweep through the frequency-range from 16.0 to 0.516 mc/sec may be used as an indication of the relative absorption of the exploring signal in the lower ionosphere. The trend in this quarter is downward, in contrast to the slight upward trend of the previous quarter. Apparently, relative absorption follows a diurnal characteristic similar to E-region ionization. Following steady night-time values, absorption increases smoothly from about 05^h to a maximum at midday, and decreases fairly smoothly to steady values at night by about 19^h. A diurnal characteristic of this nature is probably caused by a region below the E-region which is normally ionized by ultraviolet radiation, but which is invisible to radio-exploration equipment of this type.

TABLE 2—*Root-mean-square values of F_2-region critical frequencies ($f^\circ_{F_2}$), Huancayo Magnetic Observatory, October to December, 1939*

EST	Oct.	Nov.	Dec.	EST	Oct.	Nov.	Dec.
h	*mc/sec*	*mc/sec*	*mc/sec*	*h*	*mc/sec*	*mc/sec*	*mc/sec*
00	9.91	8.24	7.12	12	12.16	12.55	11.43
01	8.56	7.84	6.64	13	11.77	12.43	11.62
02	7.63	7.48	6.07	14	11.74	12.44	11.87
03	7.01	6.57	5.95	15	11.84	12.37	11.96
04	6.33	5.81	5.47	16	12.01	12.23	11.83
05	5.64	5.50	5.25	17	12.15	11.85	11.74
06	8.64	8.36	7.61	18	11.95	11.23	11.45
07	11.57	10.79	9.74	19	11.06	10.31	11.06
08	13.20	12.07	11.04	20	10.59	9.40	9.73
09	13.59	12.78	11.68	21	10.44	8.86	8.73
10	13.16	12.82	11.85	22	10.51	8.57	8.10
11	12.56	12.64	11.57	23	10.35	8.49	7.51

Table 2 gives root-mean-square values of F_2-region critical frequencies for this quarter. Since ionization is proportional to the square of frequency, these data are more representative of *average ionization* than the normally used means of critical frequencies. The difference between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 is an approximate measure of the scatter in individual observations during the month for that particular hour. Root-mean-square values for the E-region, F_1-region, and minimum frequency received have been discontinued because of the absence of appreciable differences between the root-mean-square and arithmetical-mean values.

HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, February 15, 1940

IONOSPHERIC CHARACTERISTICS AT HUANCAYO, PERU, FOR THE YEAR 1939

By H. W. Wells and R. C. Coile

Ionospheric characteristics at the Huancayo Magnetic Observatory (12° 02′.7 south, 75° 20′.4 west) of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for the year 1939 have been published in quarterly reports in this Journal [see 1 under "References" at end of paper]. The present paper is a recapitulation of the reports for the year 1939, and is a sequel to the analysis for the period December, 1937, through December, 1938 [2]. The photographic records have been obtained with multifrequency equipment sweeping over a frequency-range of 16.0 to 0.516 mc/sec every 15 minutes continuously for 24 hours each day—except for occasional short intervals necessary for maintenance—since December, 1937.

This paper continues the method of presentation used in the annual report for 1938 [2]. The figures are relief maps illustrating mean diurnal variation in critical frequency or virtual height for each region. Full lines are contours of frequency or height, and dotted lines represent the curve of mean data for the month indicated. These figures afford an effective means of distinguishing the general characteristics and month-to-month trends by casual inspection.

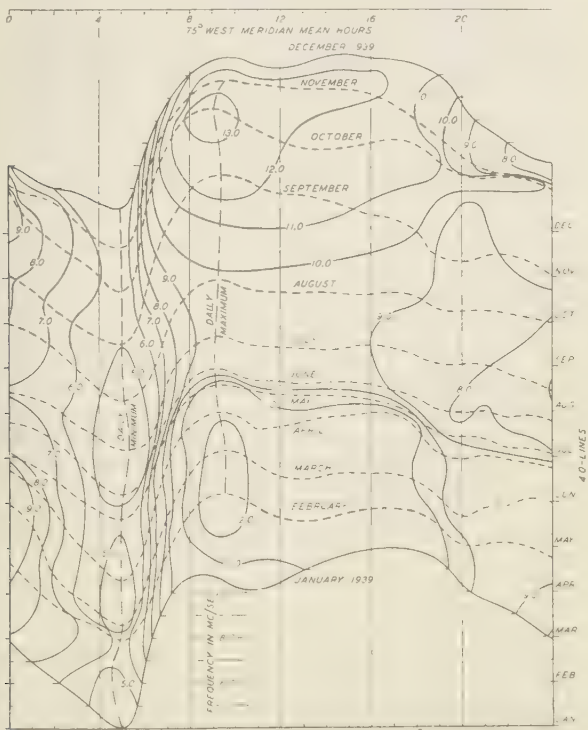


FIG. 1—SURFACE OF CRITICAL FREQUENCIES OF F_2-REGION ($f^0_{F_2}$) AT HUANCAYO, PERU, FOR THE YEAR 1939

(1) *F-region:* (*a*) *Critical frequency*—Figure 1 shows the variations of the critical frequencies of the *F*-region for 1939. This Figure, in general aspects, is very similar to the corresponding figure illustrating the critical frequencies for 1938 [2]. The results in 1938 exhibited peaks in February and November and a minimum in June. The data here considered show peaks in February and October with a minimum in July. Since maximum frequencies are usually recorded daily near 09^h (75° west meridian time), a plot of the monthly mean critical frequency at 09^h for the year is shown in graph *A* of Figure 2 to illustrate the preceding discussion more clearly.

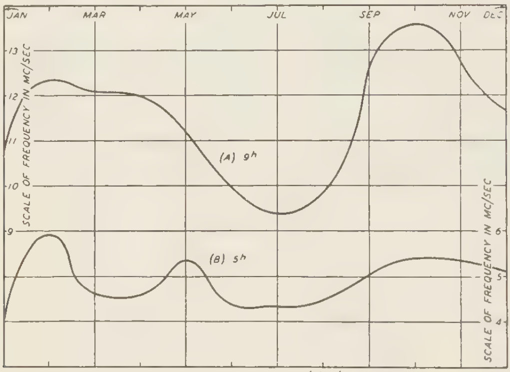


FIG. 2—AVERAGE CRITICAL FREQUENCIES AT (A) 9^h, REPRESENTATIVE OF DAILY MAXIMUM, AND (B) 5^h, REPRESENTATIVE OF DAILY MINIMUM; 75° WEST MERIDIAN HOURS, HUANCAYO, PERU, 1939

The data for 05^h for the various months have been plotted in a similar manner in graph *B* of Figure 2 to show the monthly variation of the minimum critical frequency. These data exhibit the same trends as those pointed out in the report for 1938. When the maximum critical frequencies are high, the minimum frequencies are high, and in those months when the maximum values are low, the minimum values are also low. This characteristic, in addition to the rapid increase in value of the critical frequency at sunrise, is further confirmation of the deduction from the data for 1938 that the primary ionizing force in the *F*-region is active during daylight only, in spite of the anomalous characteristics of this region at higher latitudes [3]. The dotted line on Figure 1 of the daily hour of minimum frequency shows a later hour of minimum frequency for the month of July in good agreement with the fact that July's sunrise is later than that of the other months.

Since 1939 had less solar activity than 1938, the *F*-region critical frequencies for that year are in general somewhat lower than the values measured in 1938.

(*b*) *Virtual height*—Maximum daytime virtual heights are recorded near noon as Figure 3 illustrates. These data repeat the maxima of January and July, 1938, in January and July, 1939. This corroborates the discussion presented in the report for 1938, which will be briefly summarized. The heights in Washington, D. C. (39° north), as measured

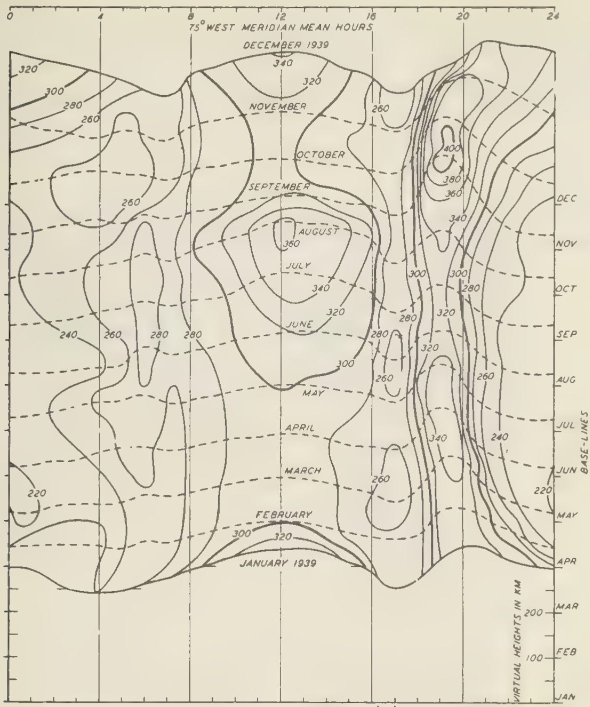


FIG. 3—SURFACE OF VIRTUAL HEIGHTS OF F-REGION (h_F) AT HUANCAYO, PERU, FOR THE YEAR 1939

by the National Bureau of Standards, show a maximum in local summer and a minimum in local winter. Results of measurements at Watheroo, Western Australia (30° south), show a maximum in local summer and a minimum in local winter. These data from Huancayo, however, are not consistent with the data for the Southern Hemisphere at Watheroo, but show minimum heights in February and October, the two times of the year when the Sun is directly overhead. This lack of seasonal effect noted in the data for 1938, and now in 1939, in addition, is contrary to what would be expected on the basis of a theory of simple heating and expansion in the upper ionosphere.

Figure 4 shows the monthly variation of maximum day heights and

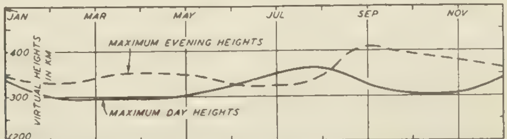
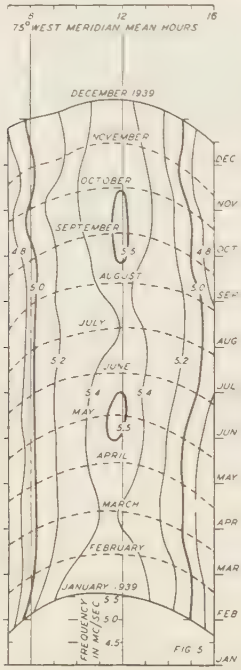


FIG. 4—CHARACTERISTICS OF MAXIMUM VIRTUAL HEIGHTS OF F-REGION FOR DAYTIME AND EVENING, HUANCAYO, PERU, FOR THE YEAR 1939

maximum evening heights. Examination of diurnal variation in Figure 3 discloses again the curious post-sunset maxima commented on in the report for 1938. These evening maxima were higher than the noon values for all months except July and August.

F-region virtual heights for 1939 were higher than those of 1938.



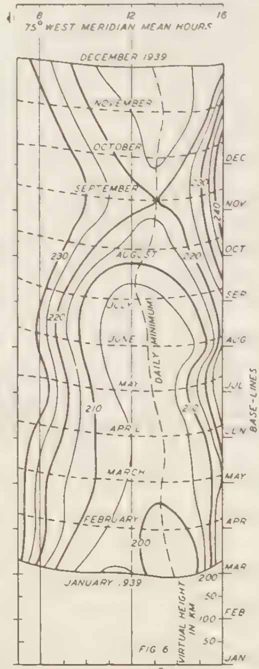


FIG. 5—SURFACE OF CRITICAL FREQUENCIES OF F_1-REGION ($f^0_{F_1}$) AT HUANCAYO PERU FOR THE YEAR 1939

FIG. 6—SURFACE OF VIRTUAL HEIGHTS OF F_1-REGION (h_{F_1}) AT HUANCAYO, PERU, FOR THE YEAR 1939

(2) *F_1-region:* (*a*) *Critical frequency*—Figure 5 which shows the F_1-region critical frequencies is very similar to the surface for 1938 except for the latter part of 1939 which has slightly lower maximum frequencies than the corresponding months of 1938. In 1938 the critical frequencies were not as clearly defined as in previous years of reduced solar activity, and it was more difficult to distinguish ordinary and extraordinary critical frequencies caused by magneto-ionic double refraction. This confirmed the opinion, also expressed in the report for 1938, that in general it seemed that the F_1-region critical frequencies are well defined when apparent heights of the F_2-region are high and F_2 critical frequencies are low, but they are poorly defined when heights of the F_2-region are low and critical frequencies are high. Since 1939 had slightly higher F_2-region heights and lower F_2-region critical frequencies than 1938, the separation of the "*o*" and "*x*" wave-components of the F_1-region critical frequencies was seen much more frequently in 1939 than in 1938.

(*b*) *Virtual height*. Figure 6 shows the surface of virtual heights for the F_1-region. In 1938 there were minima in January and August. The data for 1939 exhibit a minimum in January but a maximum in September. The previous annual report indicated that it is highly probable that characteristic trends, which are small by nature, may be masked under secular changes, especially during the period in 1939 of higher sunspot-numbers. Hence more data will be needed to determine the true characteristics, as the trends of 1938 are not followed explicitly in 1939.

The average hourly values of F_1-region virtual height representative of the whole year 1939 were almost the same in magnitude as the yearly values for 1938.

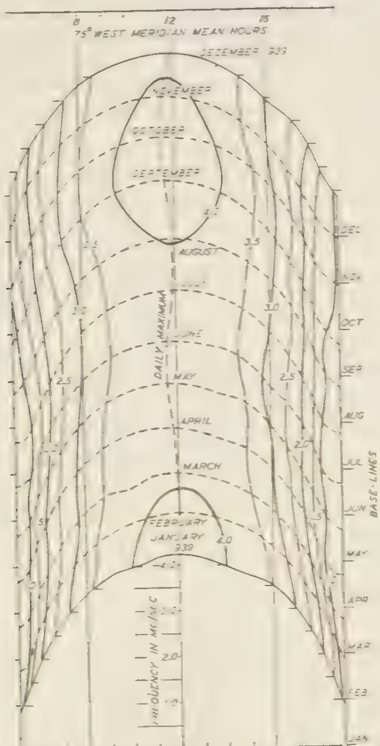


FIG. 7—SURFACE OF CRITICAL FREQUENCIES OF E-REGION (f^0_E) AT HUANCAYO, PERU, FOR THE YEAR 1939

(3) *E-region*: (*a*) *Critical frequency*—The critical frequencies for 1939 were slightly lower than those of 1938. The monthly trends are different also, since 1938 recorded a maximum in April, while 1939 had maxima in January and October, closely approximating the periods when the Sun is directly overhead at this location, which is what one would expect on the basis of ionization by ultraviolet radiation alone.

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, Year 1939*

EST	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f°_{min}	EST	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f°_{min}
h	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*h*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00		251			8.36		12	209	319	4.04	5.46	10.86	2.19
01		249			7.73		13	207	318	3.95	5.38	10.86	2.14
02		252			6.91		14	209	310	3.79	5.23	10.92	2.02
03		254			6.09		15	214	297	3.54	4.95	10.97	1.70
04		258			5.38		16	231	286	3.08	4.59	10.97	1.26
05		259	0.76		4.88	0.65	17		260	2.49		10.86	0.96
06		270	1.76		6.50	0.87	18		296	1.46		10.54	0.94
07	241	259	2.66	4.58	9.30	1.08	19		345	0.78		9.79	0.70
08	232	278	3.27	4.99	10.86	1.39	20		333			9.27	
09	222	289	3.65	5.21	11.51	1.69	21		298			9.14	
10	215	304	3.85	5.36	11.39	2.00	22		273			8.92	
11	211	314	4.00	5.43	11.01	2.14	23		259			8.75	

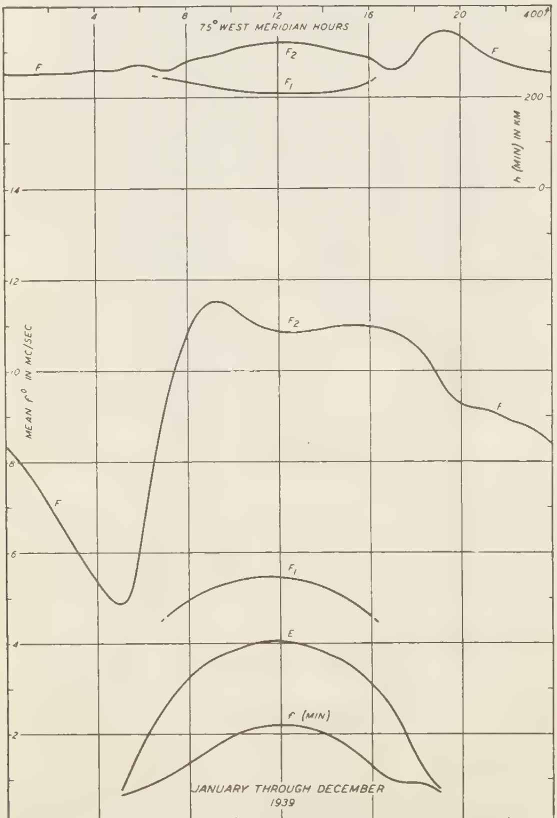


FIG. 8—MEAN CRITICAL FREQUENCY (f°), MINIMUM VIRTUAL HEIGHT (h-MIN), FOR IONOSPHERIC REGIONS FOR THE YEAR 1939, HUANCAYO, PERU

(*b*) *Virtual height*—Tabulations of the *E*-region virtual heights were discontinued in July, 1939, because of the absence of significant variations or trends within the limits of observational error of the apparatus used. At this location the height of the *E*-region remains close to 100 km through the 24 hours of the day.

The monthly averages of ionospheric data are summarized in Table 1 to give average hourly values representative of the complete year 1939. Curves for the same data are given in Figure 8. The curve below that of the *E*-region critical frequency represents the lowest frequency received, that is, the lowest frequency from which radio reflections were recorded. As such it is a measure of absorption experienced by the exploring radio signal in the lower ionosphere. Its diurnal variation is similar in general trend to that of the *E*-region ionization. This is probably caused by a region below the *E*-region which is normally ionized by ultraviolet radiation, but which is invisible to our equipment because of low height or high molecular density. Such a region may be closely related to that part of the ionosphere associated with the development of radio fade-outs.

In conclusion, the writers wish to express their sincere appreciation to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, whose active interest and support has made possible the development and successful continuous operation of such powerful investigational equipment, and to their colleagues at Huancayo and Washington for their cooperation and suggestions.

References

[1] H. W. Wells and H. E. Stanton, Terr. Mag., **44**, 321-325 (1939); H. W. Wells, Terr. Mag., **44**, 395-400 (1939) and **45**, 49-52 (1940); H. W. Wells and R. C. Coile, Terr. Mag., **45**, 155-158 (1940).
[2] H. W. Wells and H. E. Stanton, Terr. Mag., **44**, 326-334 (1939).
[3] L. V. Berkner, H. W. Wells, and S. L. Seaton, Terr. Mag., **41**, 173-184 (1936).

Huancayo Magnetic Observatory,
Huancayo, Peru, March 27, 1940

(See also page 213)

PROVISIONAL SUNSPOT-NUMBERS FOR JANUARY TO APRIL, 1940

(Dependent alone on observation at Zürich Observatory)

Day	January	February	March	April
1	*E*39[c]	. .[b]	*E* 91[c]	*E*85[c]
2	37	59	74[b]	80[a]
3	42	68	*M* 96[cd]	*E*. .[c]
4	. .	52	116[d]	47
5	. .[b]	. .[aa]	*E* 92[c]	62[a]
6	55*	*E*47[c]	. . .	58[ad]
7	. .	*E*. .[c]	77	64
8	38	64	*E* 72[c]	56
9	*M*. .[c]	*E*82[c]	46[aa]	*W*41[c]
10	41	. .	. . .	*E*59[c]
11	*E*50[c]	41[aad]	48[a]	50[a]
12	29	*M*. .[c]	*M* 76[c]	53
13	34	62	74	53
14	61	*E*89[c]	76[d]	60[d]
15	*E*33*?	. .	49	74
16	61[a]	73	*M* 70[c]	65[ad]
17	. .	51[aa]	43[a]	65
18	64	49	*M* 56[c]	59
19	59	*M*. .[cd]	78[a]	*W*71[cd]
20	*M*88[ac]	*M*. .[ac]	79[d]	79[a]
21	71[a]	60[a]	85[d]	94[a]
22	75*	59[d]	*E* 92[c]	83
23	52	44	*E*111[cd]	63[a]
24	34	40	115	*W*64[c]
25	. .[d]	44	101[a]	56[ad]
26	54*	*E*. .[c]	*E*108[cb]	50
27	. .	52	136[ad]	62
28	. .	46[a]	125	38
29	. .	*M*95[c]	98[a]	32
30	. .		86	35
31	. .		85[a]	
Means.	50.9	58.4	84.7	60.6
No. days. . . .	20	20	29	29

Mean for quarter, January to March, 1940: 67.3 (69 days).

*At temporary station of observation, Chur.
[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

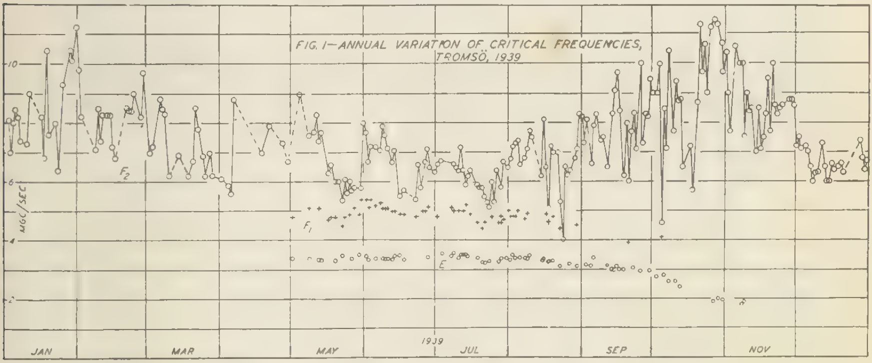
ANNUAL VARIATIONS OF THE CRITICAL FREQUENCIES OF THE IONIZED LAYERS AT TROMSÖ DURING 1939

By Leiv Harang

Regular determinations of the critical frequencies of the ionized layers, which were begun at the Auroral Observatory in April 1935[1], were continued during 1939. Regular observations were usually taken on six days during the week at 10^h, 12^h, and 14^h, local time. At Tromsö, situated near the auroral zone, the conditions of the ionosphere are strongly influenced by magnetic storms and the echoes are often lacking during disturbed periods, or more-or-less irregular and scattered echoes appear which sometimes make a precise critical-frequency determination difficult.

[1] Terr. Mag., **42**, 55-72 (1937), **43**, 41-43 (1938), and **44**, 15-16 (1939). In Pub. Inst. Kosm. Fysikk, Bergen, No. 11 (1937) and No. 14 (1938) [Results of radio-echo observations for the years 1935, 1936, and 1937], a detailed account of the daily observations at the Auroral Observatory. Tromsö, is given.

Figure 1 shows the annual variation of the noon-values of the critical frequencies for the F_2-, F_{-1}, and E-layers.



The critical frequencies for the F_1-layer are only developed during the four summer months. In Table 1 the mean monthly values of the critical frequencies are given. The general course of the annual curve is the same as that usually found for the Northern Hemisphere, with high values of the critical frequencies for the E- and F_1-layers during summer and low values during winter, whereas the F_2-layer shows an inverse annual variation with a secondary minimum about midwinter.

Compared with the preceding year, the mean monthly values for the layers show a slight decrease. For the E-layer the decrease of the critical frequencies is of the order 0.1 mc sec; for the F_1-layer the mean decrease seems to be less. The mean values of the critical frequencies of the F_2-layer show a marked decrease of 0.5-0.6 mc/sec, which is shown in Table 1.

Table 1—*Monthly mean values of critical frequencies in megacycles per second, ordinary component only, Tromsö (latitude 69°.66 north, longitude 18°.95 east), January to December 1939*

Month	Region and local time								
	E			F_1			F_2		
	10^h	12^h	14^h	10^h	12^h	14^h	10^h	12^h	14^h
1939									
Jan.							6.54	8.50	7.83
Feb.							7.40	8.25	8.09
Mar.							6.43	7.23	6.83
Apr.		3.40			4.90	4.10	7.10	6.91	6.93
May	3.30	3.86	3.25	4.83	4.92	4.86	7.03	6.72	6.61
June	3.34	3.42	3.34	5.03	5.09	4.88	6.69	6.76	6.44
July	3.36	3.41	3.37	4.81	4.75	4.71	6.25	6.18	6.13
Aug.	3.25	3.33	3.29	4.63	4.68	4.74	6.69	6.89	6.69
Sep.	2.87	2.95	2.80				7.57	7.94	8.04
Oct.	2.44	2.37	2.28				8.57	9.21	8.33
Nov.	1.78	1.85	1.65				7.29	8.54	8.11
Dec.							5.28	6.64	5.86
Mean values, 1939							6.90	7.48	7.16
Mean values, 1938							7.45	8.05	7.77
Decrease from 1938 to 1939							0.55	0.57	0.61

The maximum values of the critical frequencies of the ionized layers appeared in 1937. The observations during 1938 and 1939 show a continuous decrease of the values, which indicates that the maximum of the sunspot-cycle has been passed.

Auroral Observatory,
Tromsö, Norway, January 1940

THE IONOSPHERE AT WATHEROO, WESTERN AUSTRALIA, OCTOBER TO DECEMBER, 1939

By W. C. Parkinson and L. S. Prior

The information contained in this report is similar in character to that supplied for previous months.[1] Table 1, as before, gives the mean hourly values of minimum virtual height and critical frequency of the *o* wave-component for the ionospheric regions for each hour during October, November, and December 1939, over those periods of the day when these values are scaled. It also includes mean hourly values of the lowest frequency recorded, f_{min}, when this frequency exceeded the lower limit of the frequency-sweep, namely, 16.0 to 0.516 megacycles per second. Figure 1 gives the data of Table 1 in graphical form. The 120° east meridian standard times of sunrise and sunset are shown on the graphs by broken vertical lines, these times being for the middle day of the month involved.

Table 2 gives the mean hourly values of ionospheric data for the whole year 1939 and Figure 2 shows the curves derived from these data.

Table 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory October to December, 1939*

120° east mean time	h_{F_1}	h_{F_2}	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
			October, 1939			
00		274			6.66	
01		261			6.27	
02		259			5.70	
03		279			5.28	
04		294			5.11	
05		309	1.12		5.11	
06		277	2.22		6.61	0.58
07	242	256	2.81	4.22	8.05	0.73
08	232	273	3.27	4.89	8.94	0.92
09	228	280	3.56	5.15	9.47	1.00
10	217	309	3.70	5.42	10.07	1.15
11	214	324	3.80	5.53	10.56	1.14
12	221	313	3.84	5.54	10.94	1.25
13	229	310	3.81	5.42	11.12	1.16
14	228	304	3.75	5.34	10.89	1.12
15	235	287	3.57	5.10	10.61	1.08
16	237	278	3.21	4.64	10.16	0.87
17	254	260	2.59	4.28	9.95	0.72
18		251	1.90		9.62	0.60
19		242	0.95		8.86	
20		247	0.83		8.19	
21		259			7.49	
22		270			7.11	
23		277			6.85	

[1] Terr. Mag., **44**, 199-204, 341-343, 401-403 (1939), and **45**, 45-47 (1940).

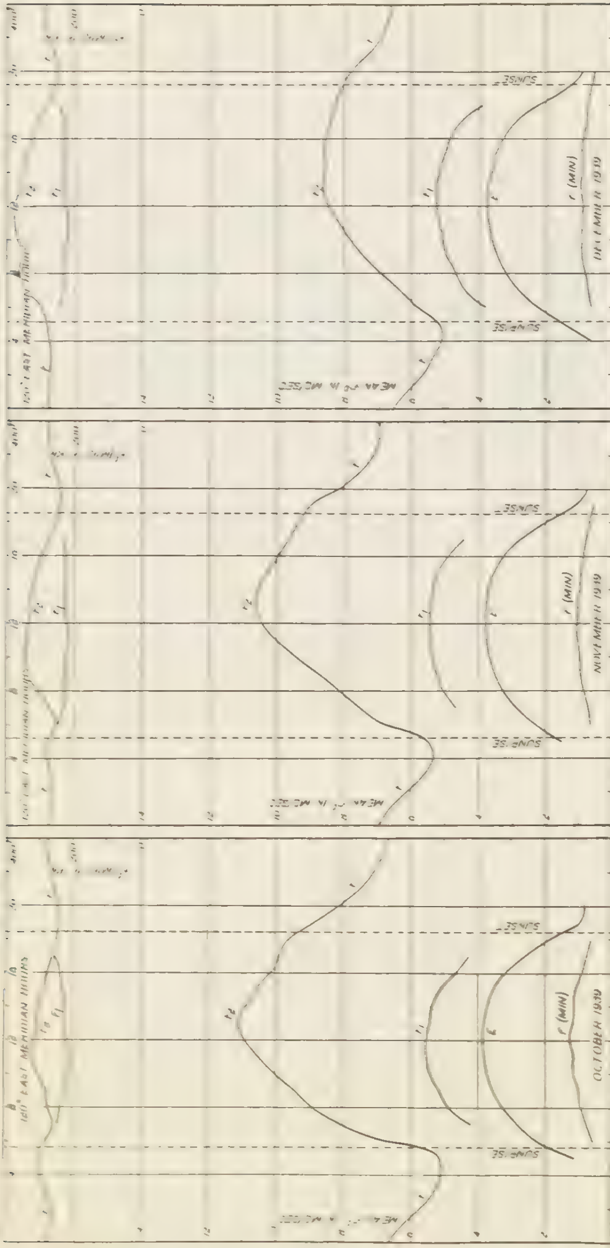


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0 MIN), FOR IONOSPHERIC REGIONS, OCTOBER, NOVEMBER, AND DECEMBER, 1939, WATHEROO, WESTERN AUSTRALIA

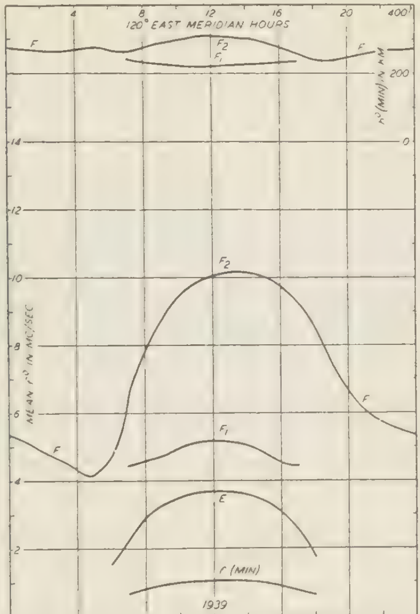


FIG. 2—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, 1939, WATHEROO, WESTERN AUSTRALIA

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, October to December, 1939*—Concluded

120° east mean time	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
			November, 1939			
00		277			6.95	
01		266			6.67	
02		265			6.12	
03		270			5.67	
04		278			5.37	
05		275	1.51		5.50	
06	245	252	2.34		6.82	
07	231	271	2.90	4.68	7.52	0.67
08	229	307	3.29	5.08	8.14	0.74
09	228	342	3.53	5.25	8.78	0.86
10	224	343	3.66	5.38	9.43	0.96
11	215	341	3.77	5.42	10.03	0.98
12	221	334	3.79	5.45	10.45	1.01
13	228	334	3.78	5.42	10.61	1.03
14	224	321	3.72	5.34	10.59	1.02
15	228	314	3.54	5.23	10.29	0.98
16	228	297	3.25	4.89	9.95	0.92
17	232	272	2.76	4.40	9.65	0.86
18		253	2.02		9.36	0.74
19		243	1.14		9.04	0.68
20		243	0.78		8.16	0.55
21		260			7.57	
22		272			7.15	
23		277			6.96	

December, 1939

00		276			6.57	
01		273			6.17	
02		271			5.66	
03		268			5.41	
04		273	0.65		5.11	
05		279	1.44		5.17	
06	249	296	2.29	3.81	5.85	0.66
07	236	343	2.82	4.46	6.34	0.74
08	234	362	3.20	4.70	6.91	0.83
09	233	352	3.46	4.98	7.42	0.91
10	220	366	3.60	5.07	7.82	0.92
11	219	371	3.70	5.18	8.19	0.92
12	222	376	3.74	5.21	8.48	0.90
13	228	358	3.74	5.25	8.64	0.94
14	231	354	3.59	5.18	8.58	0.93
15	227	339	3.51	5.00	8.58	0.93
16	227	324	3.26	4.84	8.56	0.87
17	227	306	2.90	4.50	8.40	0.78
18	244	272	2.23	3.87	8.29	0.74
19		254	1.39		8.08	0.61
20		250	0.88		7.78	0.51
21		258			7.26	
22		273			6.86	
23		281			6.68	

Table 2—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, year 1939*

120° east mean time	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00		272			5.35	
01		269			5.12	
02		266			4.83	
03		264			4.60	
04		267			4.35	
05		274			4.18	
06		266	1.53		4.68	
07	238	262	2.35	4.43	6.45	0.69
08	232	277	2.94	4.61	7.92	0.83
09	228	288	3.30	4.75	8.83	0.94
10	221	299	3.51	4.98	9.48	0.99
11	218	307	3.63	5.12	9.88	1.02
12	220	308	3.69	5.16	10.05	1.04
13	222	306	3.68	5.14	10.15	1.04
14	225	302	3.59	5.04	10.14	1.01
15	229	290	3.41	4.80	10.05	0.97
16	231	275	3.07	4.52	9.71	0.87
17	235	259	2.52	4.46	9.28	0.75
18		241	1.74		8.59	0.63
19		238			7.51	
20		245			6.67	
21		256			6.08	
22		267			5.72	
23		269			5.51	

Watheroo Magnetic Observatory,
Watheroo, Western Australia, January 26, 1940

ANALYSIS OF LOCAL ATMOSPHERIC-ELECTRIC PHENOMENA AT COLLEGE, ALASKA

By O. H. Gish and K. L. Sherman

Abstract—The atmospheric-electric data obtained at College, Alaska, during the International Polar Year have been analyzed in order (1) to separate the universal and local features in their diurnal variation and (2) to compare them with the theory of the electrode-effect. After eliminating the universal diurnal-variation component from the potential-gradient a local component remains. In winter this local component is largely the result of variations in the conductivity near the Earth's surface but in summer there is no correlation between these elements. The calculated ratio of the columnar resistance of the air over College to that over the oceans shows a diurnal variation. The statistical significance of this variation is questioned. If it is significant various hypotheses which could account for such a variation are considered.

The diurnal variation in positive conductivity retains its character throughout the year although its amplitude is about 50 per cent less in summer than in winter. Its variations are attributed chiefly to variations in q and N. In contrast the diurnal variation of negative conductivity changes markedly from summer to winter. The negative conductivity depends greatly on the field in winter whereas in summer the increased wind or factors closely associated with it effectively oppose the action of the field.

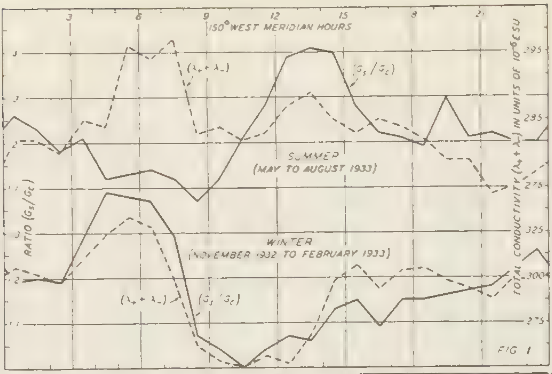
The theory of the electrode-effect is reviewed and amplified. Following the method of Scholz additional relations based on both the large- and small-ion theory are developed so that a variety of conditions are covered. Some of the results are presented graphically for ease in comparing with these and other results. The air at College was very quiet in winter and apparently met this restriction of the theory for the results obtained then are shown to be in satisfactory quantitative agreement with the theory.

Introduction—That atmospheric-electric phenomena in polar regions are simpler than those generally observed at stations on land elsewhere and that these bear a considerable resemblance to the corresponding features observed at sea during fair weather was indicated by observations which were available before the Second International Polar Year.

The data obtained at College, Alaska, during that year, from a more complete program of atmospheric-electric observations than had hitherto been carried out at a high-latitude station, corroborated that indication as is to be seen from a summary of the general results which was published in an earlier number of this Journal [see 1 of "References" at end of this article]. However, there are some significant departures which are attributable to local factors. Descriptions and analyses of some of these local components are given in this report.

ANALYSIS OF THE DIURNAL VARIATION OF POTENTIAL-GRADIENT

Local diurnal variation of potential-gradient—It was shown in a previous report [1] that in the average the diurnal variation of the potential-gradient at College is very similar to that over the oceans (see graphs in Figure 6 and the summary of Fourier analyses in Table 3 of that report). However, when these data are examined more closely, some significant differences are to be seen. These differences are exhibited in the two full-line graphs of Figure 1 of this article. The ordinate in each of these graphs is the ratio (G_s/G_c) of the gradient at sea to that at College. The abscissa is the number of hours after local midnight. The values used here for the gradient at sea [2] are means, for the respective hours of the day, derived from data obtained on the several cruises of the *Carnegie* for rather critically selected days. The values for College are means for all days on which complete records were obtained in the respective seasons. The departure of each of these graphs



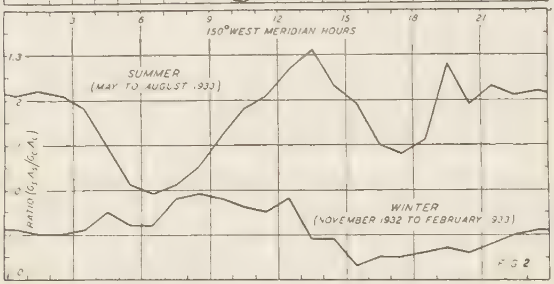


FIG. 1—RATIO OF AVERAGE HOURLY POTENTIAL-GRADIENT OVER OCEANS (G_S), CARNEGIE 1915-29, TO THAT FOR ALL COMPLETE DAYS AT COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION (G_C), AND SUM OF AVERAGE HOURLY POSITIVE AND NEGATIVE AIR-CONDUCTIVITY ($\lambda_+ + \lambda_-$) FOR ALL COMPLETE DAYS AT COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION

FIG. 2—RATIO OF AVERAGE HOURLY CURRENT OVER OCEANS ($G_S\Lambda_S$), CARNEGIE 1915-29, TO THAT FOR ALL COMPLETE DAYS AT COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION ($G_C\Lambda_C$)

for (G_s/G_c) from a straight line is regarded as a measure of the local influences which affect the gradient at College.

The considerations upon which such an interpretation depends are as follows: The Earth is regarded as the central element of a spherical condenser and the high atmosphere as the other element. It is known that the conductivity of the Earth, as well as that of the ionosphere, is great enough so that the surface of the Earth and some other surface, say, in the ionosphere or possibly at some lower fixed level, each may be regarded as an equipotential surface, the difference in potential between these surfaces at any instant being V. Furthermore, the mean diurnal variation of the gradient at sea is regarded as being purely universal and therefore of the same character as the diurnal variation in V, or that in i_s $(=\lambda_s G_s)$ the vertical electrical conduction-current density at sea. The evidence upon which these assumptions depend shall not be reviewed again here further than to state that little if any diurnal variation in the conductivity, λ_s, near the surface has been found [16]. At many stations on land apparently not all of the foregoing assumptions are valid. The gradient there, say G_c, and the conductivity, λ_c, both generally undergo a marked diurnal variation. The conduction-current density, $i_c=\lambda_c G_c$, may vary more than that at sea, but generally the

variation in this element is more nearly the same for land and sea than is the case for the gradient. When in a given region a change in conductivity extends to a height sufficient to appreciably change the resistance, R_c, of a vertical column of air of unit cross-section and extending from the Earth to the highly conducting region of the atmosphere, then it is expected that the conduction-current in that region will be modified also. It is assumed for the present that over land as well as over the oceans the vertical electric current is wholly a conduction-current, namely, that $i=\lambda G=(V/R)$ at all places. The validity of this generally accepted assumption shall be examined briefly later on. For the circumstances which have been outlined here, the following simple relations hold: $i_s=\lambda_s G_s=V/R_s$; $i_c=\lambda_c G_c=V/R_c$; and since V is assumed to be the same in the two cases $\lambda_s G_s R_s=\lambda_c G_c R_c$ or $(G_s/G_c)=(\lambda_c R_c)/(\lambda_s R_s)$. Since there are good grounds for regarding λ_s and R_s as constants, at least in so far as concerns the average diurnal variation, one may infer that variations in the ratio (G_s/G_c) are an indication of corresponding variations in either or both λ_c and R_c. Since λ_c and R_c both may depend upon position, (G_s/G_c) serves as a measure of the *local* component in the diurnal variation of the gradient.

The graphs of Figure 1 show that such variations occur at College in both summer and winter, the range being about 30 per cent of the mean in each season. However, the character of the graph changes considerably with season.

These graphs may be compared with graphs of similar significance derived from potential-gradient data for most places where such measurements have been made. Scrase [3] first published such a graph, based on the data obtained at the Kew Observatory. Brown [4] later published graphs having about the same significance, although derived by a different method, for 22 different places. Brown says that "If we examine the local diurnal variations of the gradient at the various land-stations we find that the portions of the curves extending from about 8 p. m. to 8 a. m. are very similar at all stations at all times of the year." One wonders, when examining his graphs, whether the author's meaning is clearly expressed in this statement. If one should say that most of the curves are of somewhat similar character during that period, the apparent exceptions, especially Watheroo, Eskdalemuir and Cape Evans, would present less occasion for perplexity. The data for College seem to present another exception, especially in that the graph for summer differs radically from that for winter in all its significant features. The entire graph for College in the winter season does bear a considerable resemblance to the corresponding graph for Stanford. The graph for summer at College shows some resemblance to that published by Brown for Potsdam. When comparing the graphs for (G_s/G_c) in Figure 1 with that of Scrase or those of Brown, it is to be noted that a minimum, or a maximum, in their graphs is to be compared with a maximum, or a minimum, respectively, on these graphs. Since such comparisons of complex geophysical phenomena at different places and for different periods of time have often been misleading, it is of doubtful value to extend this further until it is possible to make a reliable test of the significance of the apparent correlations.

The rôle of diurnal variation in conductivity—It has already been seen that for the conditions mentioned in an earlier paragraph the local variation in gradient is proportional to the variation of the product

$\lambda_c R_c$. Since λ_c has been determined for College, it seems feasible to ascertain the relative importance of these two factors. The diurnal variation of total conductivity ($\lambda_c = \lambda_1 + \lambda_2$) at College for the summer and for the winter season is shown by the broken-line graphs in Figure 1. It is easily seen by inspection of the graphs of (G_s/G_c) and λ_c that, for the summer months, there is very little if any dependence of the former upon the latter during that season. In fact, the coefficient of correlation between the two series of 24 hourly values is -0.11. One may therefore infer that the diurnal variation in the ratio (G_s/G_c) during the summer at College may be largely a result of variations of the columnar resistance (R_c). The latter in turn is thought to be the result of changes of the conductivity of the air up to an altitude of several kilometers. However, the character of the apparent changes in R_c are not reflected in the changes of conductivity at the surface. This is regarded as evidence that the main part of these changes in R_c are not brought about by turbulent mixing (eddy-diffusion) or convection in the stratum of air adjacent to the Earth. Although the correlation between the diurnal variation of negative conductivity and that of wind-velocity in summer shown in Figure 4 is doubtless chiefly ascribable to a diurnal variation of eddy-diffusivity, yet this certainly extends to a relatively small distance from the Earth and can scarcely be concerned with real variations of R_c. At this stage of analysis it seems likely that the apparent diurnal variation of R_c in summer must depend upon factors which are active higher in the atmosphere but are inactive in the surface-stratum. This tentative conclusion has such important implications that it shall be examined further in a later paragraph.

In winter the diurnal variation in the ratio (G_s/G_c) is largely dependent upon the variations of conductivity near the Earth's surface. The evidence for this is exhibited by the two graphs in the lower part of Figure 1. In this case the coefficient of correlation between the two sets of 24 hourly values is $+0.87$. This is such a high correlation for data of this sort that the significance of it can scarcely be questioned. One may therefore conclude that the resistance, R_c, at College in winter suffers relatively little variation during the day and that the prominent departures of the diurnal variation of the gradient from the universal character are due to the diurnal variation of the conductivity of the air in a relatively shallow stratum adjacent to the Earth. The latter will be analyzed in a later section. The relative columnar resistance (R_c/R_s) for the two seasons may now be examined in a somewhat more direct manner.

The rôle of variation in columnar resistance—It will be seen from the relation discussed in a previous paragraph that $(\lambda_s G_s)/(\lambda_c G_c) = (R_c/R_s) = (i_s/i_c)$. Values of this ratio were formed from values of λ and G observed at sea on the several cruises of the *Carnegie* and from values of these elements recorded at College. Values of i_c were formed for each hour of available record for the respective seasons and the means for each of the 24 hours of the day were used here. However, the *Carnegie* data could not be combined in this way because there are not available sufficient records of the diurnal variation of conductivity at sea. Instead, the mean hourly values of gradient for each season were multiplied by a constant value of conductivity, namely, 2.54×10^{-4} esu, which is the value that would correspond to a mean gradient of 130 v/m and a mean current-density of 11×10^{-7} esu. It is not expected that this procedure

will introduce any spurious periodic effect with an amplitude greater than ±4 per cent because if there is any diurnal variation in the conductivity at sea the data indicate that this has an amplitude not greater than four per cent of the mean. The error in the mean value for the day of the ratios derived in this way may be greater, but in so far as can be ascertained from the information now available this should not exceed ten per cent.

The values of the ratio (i_s/i_c) are charted as ordinates, against the number of hours after local midnight, in Figure 2 (those for summer in the upper and those for winter in the lower part). The daily mean relative columnar resistance for College appears to be greater than unity, that for summer (1.16) being only five per cent greater than that for winter (1.11). The diurnal variation in summer is, however, greater than that for winter, the former having a range of about 28 and the latter about 14 per cent of the mean. In summer this resistance is comparatively constant at about 1.2 for a period of six hours centering on midnight, namely, from about 21^h in the evening until about 3^h in the morning, but during the rest of the day it varies in a fairly regular manner, decreasing to the principal minimum (0.99) at $6^h.5$, then steadily rising to the principal maximum (1.31) at $13^h.5$, after which there is a steady drop to the secondary minimum (1.08) at $17^h.5$. While no theory that satisfactorily accounts for this has been developed, an outline of the several hypotheses which have been examined may have points of interest.

For its bearing on the possible *rôle of eddy-diffusion* in the lower atmosphere, it is noted that the principal minimum may be somewhat modified by the rather marked increase of conductivity between 5^h and 8^h, and that there may also be slight evidence of a similar relation toward the end of the day (17^h to 21^h). These cases are of such character that one might think eddy-diffusion has affected the vertical distribution of conductivity to such an altitude that the columnar resistance is modified thereby, but conditions are generally not favorable for that at those times of the day. The main features of this graph, however, do not seem explainable in terms of that process. This impels one toward the view that the factors which give rise to these features are at play in strata which are more or less remote from the Earth's surface but probably not nearly as far away as the ionosphere. The latter restriction depends on the following argument. Since normally about 0.9 of the columnar resistance appears to be provided by the lower ten km of the atmosphere, it follows that a rather drastic reduction of the conductivity throughout a considerable range of the higher altitudes would be required to account for the indicated change in columnar resistance, especially that indicated for the middle of the day.

If the *concentration of nuclei in the higher atmosphere* should vary with a suitable diurnal period, that could account for the observed variation of R_c. While it is likely that nuclei are formed at the atmospheric levels where ozone is formed, as was suggested by the decrease in conductivity from the 18- to the 22-km level observed on the flight of *Explorer II* [5], yet it is doubtful whether there would be a sufficient change in conductivity as a result of this and, furthermore, it is at least not obvious that the concentration of these nuclei could change during the day in the manner required to account for the indicated change in resistance. The increase during daylight could perhaps be regarded as a simple

function of the elevation of the Sun, but it is scarcely expected that nuclei would be dissipated at a rate such that the concentration would follow the elevation of the Sun with so little lag as seems to be indicated here.

Another hypothesis which may deserve mention here involves the assumption that V at College differs from that at sea in a periodic manner. Some observers have expressed the opinion that there is an association between auroral activity and variations in the electric field of the atmosphere. A few others have shown what they regarded as evidence of a correlation between the latter and magnetic activity. The irregular variations of the atmospheric-electric field at College showed no conspicuous correspondence with any aspect of auroral or magnetic activity, but it has been noticed that the graphs for the diurnal variation in resistance (Fig. 2) resemble those of the horizontal electric gradient in the Earth (earth-current gradient) at College [see Fig. 4 of reference 6]. For both phenomena the diurnal range in summer is between two and three times that for winter and corresponding graphs are approximately in phase if the appropriate sign for earth-potentials is used. Although the thesis that this apparent correlation has physical significance cannot be defended at this stage, yet one may point out that a surface-charge is maintained, by the electric current in the Earth, at a boundary between regions which differ in electrical conductivity. This surface-charge varies with a diurnal period similar to that of the earth-current, but its magnitude is probably too small to be appreciable in measurements of the potential-gradient in the atmosphere, except possibly in some very extreme circumstances as, for example, at the boundary between a large body of salt water and a land-area made up of well-consolidated crystalline rock.

The circulations of electric current in the high atmosphere, which give rise to the diurnal variations of the Earth's magnetic field, also doubtless maintain space-charge in some portions of the atmosphere—particularly over the equator and over the polar regions. In this case also a diurnal variation in the gradient at the Earth's surface might be expected provided that space-charge is great enough. That provision cannot be examined at this time. These remarks will suggest why it seems desirable to give further attention to the hypothesis to which they refer.

One more hypothesis that was considered involves a denial of the assumption that the vertical electric current in the atmosphere is wholly an electric conduction-current. If electricity is appreciably transported toward or away from the Earth by other means, say, for example, by eddy-diffusion, then in the steady state, for which the space-charge density does not vary with time, the sum of the electrical conduction-current and the "convection-current" which flows along the normal to the Earth across a given area must not vary with altitude. If the convection-current is brought about by eddy-diffusion, that component is expected to practically vanish at the Earth's surface and also at high altitudes because eddy-diffusion tends to vanish at the surface and on the average the gradient of space-charge density tends to vanish as the altitude increases. The result of this is that at intermediate levels the conduction-current exceeds that at the surface or at high levels by an amount equal to the convection-current. One would like to know

whether the convection-current and its variation during the day may be large enough to introduce an appreciable component of such origin in the diurnal variation of the conduction-current. Although an appreciable effect of eddy-diffusion upon the negative conductivity seems to be indicated by the correlation between the latter and wind-velocity (Fig. 4), yet the data required definitely to answer this particular question are not available for College. No appreciable convection-current was detected in special experiments at the Kew Observatory, England [9], or at Glencree, Ireland [8]. The only place for which there are available the data requisite for calculating the magnitude of the convection-current near the Earth's surface is Stanford, California, where the space-charge was registered continuously for one year at two elevations, namely, one meter and 15 meters [4, 7]. The diurnal variation in wind-velocity in the vicinity is also given in these reports so that the eddy-diffusivity at a given level for any hour of the day may be estimated for certain assumed values of the "roughness parameter." Even for what is probably a large value of the latter for Stanford, namely, 20 cm, the maximum conduction-current that can be derived from the Stanford data is only about 100 e cm^2 sec or 5×10^{-5} esu. This is estimated to be less than 20 per cent of the electric conduction-current at Stanford, and is only about five per cent of the conduction-current density found at College, at sea, and at other places where the disturbing effect of pollution is small. Perhaps the possibility that the roughness parameter is greater than that used here should be considered. Rossby and Montgomery [10] find this parameter to be less than five cm. near Boston, except for winds blowing from moderately rough country in the quadrant to the northwest of the station. For winds from that quadrant a value as great as 180 cm may perhaps be allowed. For such a value the convection-current at Stanford would be an important element. Although these considerations seem to provide no definite support for the hypothesis that the diurnal variation in the apparent columnar resistance at College may be attributed to a diurnal variation in the convection-current, neither do they demonstrate that this hypothesis can be ignored. Qualitatively such an hypothesis has some attractive features. One of these is that the effect could be brought about within a relatively shallow stratum extending from the surface to only some tens of meters, whereas if this hypothesis cannot be sustained then it is necessary to conclude either (*a*) that there is a diurnal variation in the conductivity of the air in a stratum extending up to an altitude of several kilometers, but excluding a shallow stratum adjacent to the Earth, or (*b*) that there are surprisingly large diurnal changes of conductivity at yet higher levels, or (*c*) that space-charge in the high atmosphere varies in a periodic manner during the day.

Thus far, the discussion of Figure 2 bears more specifically upon the diurnal variation of $(i_s \; i_c)$ in summer. The range of the diurnal variation of that ratio in winter is only about half that for summer and there is a marked difference in character. The first impression was that the apparent variation in winter is probably not significant but no satisfactory objective test for this has been made. However, it should be pointed out that the character of this graph may be almost completely accounted for if it is assumed that the current at College is exactly equal to that at sea for the same hour of the Greenwich day but that the values

used here for the current at sea, while in correct phase, differ from the appropriate values in the following respects: (*a*) The mean value is 11 per cent too large; (*b*) the amplitude of both the first and second harmonic is 30 per cent too large. The first-mentioned difference may be admissible but the second is somewhat larger than seems to be indicated by the scatter of the coefficients of the various harmonic analyses for different seasons and for different cruises. It was more surprising to find, when the graph for summer was considered from the same point of view, that there appeared to be nearly as much ground for questioning its significance as in the case of the graph for winter. This is to be seen by a comparison of the results of harmonic analyses of i_s and i_c for both summer and winter which are given in Table 1. Although this considera-

Table 1—*Summary of harmonic analyses of diurnal variation of air-earth current on Carnegie and at the College-Fairbanks Polar-Year Station*
(Phase-angles are based on Greenwich mean time)

Season	Location	Phase-angles		Amplitudes				Mean
		ϕ_1	ϕ_2	C_1		C_2		
		°	°	units of 10^{-8} esu	per cent	units of 10^{-8} esu	per cent	units of 10^{-8} esu
Winter	*Carnegie*	199	262	19.7	17.0	5.5	4.7	116
	College	204	292	13.0	12.5	3.9	3.8	104
Summer	*Carnegie*	155	192	11.4	12.0	6.2	6.5	95
	College	170	267	13.7	16.7	6.1	7.4	82

tion of the significance of the graphs of Figure 2 is not decisive, it does suggest that one should make considerable allowance for the possibility that some features of these graphs may be spurious.

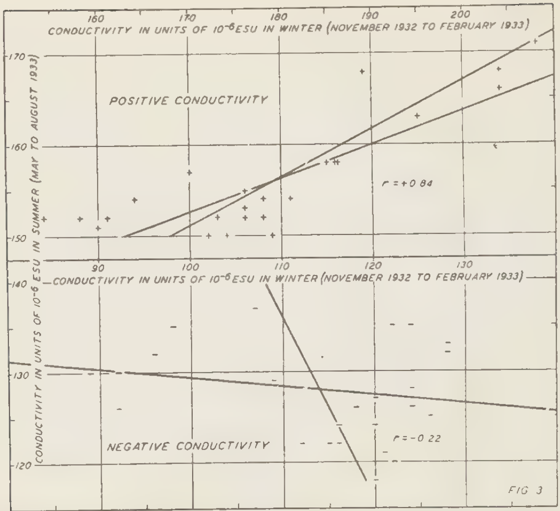
Summary—The results of this examination of the local diurnal variation of potential-gradient at College are as follows: (*a*) Although an inspection of the graphs in Figure 2 gives one the impression that these must be significant, especially that for the summer season, yet an examination of the harmonic analyses of the two elements (i_s and i_c) from which the ordinates of those graphs were derived somewhat shakes one's confidence in that impression, and emphasizes that a more exhaustive statistical examination is required to settle this point. However, if these are significant, then (*b*) there arises the question whether an electric convection-current should be considered as a factor responsible, in whole or in part, for the phenomena represented by these graphs. Although the available information which bears on this question points toward a negative answer, yet a contrary answer is not definitely excluded. If the negative answer is accepted and if the data have statistical significance, then (c) the diurnal variation of the ratio (i_s i_c) must be attributed to factors that are active throughout a considerable vertical extent of the atmosphere but not in the stratum adjacent to the Earth. Two possibilities which come under this category are as follows: (1) A space-charge, which varies with a diurnal period, is maintained in the high atmosphere, possibly by the same mechanism that gives rise to diurnal variations in terrestrial magnetism. (2) The effective resistance

of a vertical column of air, extending from the Earth up to a height where the air may be regarded as a perfect conductor, varies with a diurnal period. This may depend upon changes in the concentration of nuclei brought about either by changes in the air-circulation throughout a considerable vertical extent of the troposphere but not including the air near the Earth's surface, or it may depend upon changes in the rate at which nuclei may be formed at some high level in the atmosphere, possibly in the stratosphere.

If the assumptions which underlie this last category are valid, then one may, by the analysis followed here, differentiate between two components of the local diurnal variation of gradient, namely, (*a*) one due chiefly to variations of the conductivity of the air in a relatively shallow stratum adjacent to the Earth, and (*b*) one which is due chiefly to variations of conductivity or possibly of space-charge at higher levels and which extends throughout a considerable portion of a vertical column. The former type predominates at College in winter and the latter predominates there in summer. The local variation of gradient in summer is, in large part, independent of the corresponding variation of conductivity, whereas the correlation between these elements is high in winter. It is concluded that the mechanism to which the greater part of the local variation in summer may be attributed must be one which is not appreciably active in the air adjacent to the Earth. This seems to be an important restriction upon speculations as to the nature of that mechanism. Escape from this restriction is possible only if the apparent diurnal variation in (i_s/i_c) can be shown to be either (*a*) a manifestation of a vertical electrical convection-current or (*b*) a purely mathematical result without physical significance. In the latter case the local diurnal variation in both summer and winter should be explainable largely in terms of variations of conductivity, but this holds for the winter season in any case. An analysis of the diurnal variation and some other variations of conductivity may therefore be expected to throw further light upon the variation of the gradient.

VARIATIONS IN CONDUCTIVITY

Positive conductivity—The diurnal variation in positive conductivity at College has a well-defined character which undergoes little change from season to season as can be seen by comparing the graphs of the diurnal variations for the different seasons [see Fig. 7 of reference 1]. This is also brought out by the comparison shown in the upper portion of Figure 3 of the present report. There each of the 24 hourly means for all complete days in summer are plotted as ordinate against the corresponding value for winter as abscissa. The two least-square regression-lines, obtained when infinite weight is given to one or the other of the coordinates, are shown here. These indicate that the amplitude of the diurnal variation decreased about 50 per cent from winter to summer. The linear correlation-coefficient corresponding to the two regression-lines is +0.84. This indicates that the diurnal variation in positive conductivity is largely associated with "local clock time" and hence, it seems, must depend upon factors which vary according to a time-schedule that changes very little from winter to summer rather than upon factors such as turbulence and convection



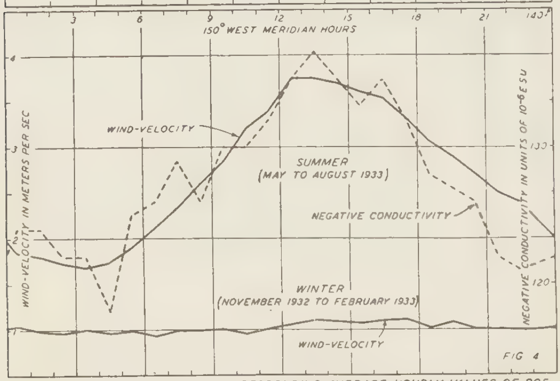


FIG. 3—COMPARISON BETWEEN CORRESPONDING AVERAGE HOURLY VALUES OF POSITIVE AND NEGATIVE CONDUCTIVITY FOR ALL COMPLETE DAYS AT COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION

FIG. 4—AVERAGE HOURLY WIND-VELOCITY FOR ALL DAYS, UNITED STATES WEATHER BUREAU STATION, FAIRBANKS, ALASKA, AND NEGATIVE CONDUCTIVITY FOR ALL DAYS, COLLEGE-FAIRBANKS (ALASKA) POLAR YEAR STATION

which, as records of wind-velocity and temperature indicate, would follow quite different schedules in the different seasons.

According to the theory of the "electrode-effect" in quiet air, which is to be discussed later, the distribution of positive small ions near the surface is modified only to a minor extent by factors which determine this effect. The greater space-charge there is chiefly attributable to the depletion of negative ions. Accordingly, one may expect that the distribution of positive ions may not be greatly altered when, instead of quiet air, turbulent mixing (or stirring) comes into account. It therefore seems likely that the diurnal and annual variations in positive conductivity are due chiefly to variations in q and N. Although measurements for determining the diurnal variation of these elements were not

made, hourly values as calculated by a method described later are shown in Figure 7. In the next section it will be noted that, in addition to the factors affecting the positive conductivity, the negative conductivity depends also upon the gradient and upon factors associated with wind.

Negative conductivity—That the diurnal variation in negative conductivity in summer was not at all similar to that in winter is evident from the graphs of Figure 7 in the previous paper. This is also emphasized by a comparison similar to that made for the positive conductivity and shown in the lower part of Figure 3. The linear correlation-coefficient between the 24 hourly values is only -0.22, which is in striking contrast with that for the positive conductivity, $+0.84$. Therefore, in an explanation of this it seems necessary to look to factors whose diurnal variation in summer differs from that in winter. That wind-velocity is such a factor is revealed by a comparison of values of negative conductivity with the corresponding hourly registrations of wind run at the near-by meteorological station in Fairbanks. The latter data were kindly made available by the United States Weather Bureau. The average hourly values derived from all days in the summer and winter seasons, respectively, are shown in Figure 4. (The anemometer was located at a height of 44 feet till July 1, 1933, when the height was increased to 87 feet.) For the winter season the extremely low average values of wind-velocity and the absence of any definite diurnal variation, and for the summer season the increased average value and the pronounced diurnal variation, are especially to be noted. The similarity of the diurnal variation in wind-velocity and that of negative conductivity in summer is at once apparent. The linear correlation-coefficient between the 24 corresponding average hourly values of negative conductivity and wind-velocity for that season is $+0.89$. Hence, an increase in wind-velocity, or a corresponding change in factors associated with that meteorological element, may doubtless be regarded as a very effective cause of the increase in negative conductivity in summer at College. A point of interest in this connection is that during the night in summer the ratio of the conductivities varies with the gradient till about 5^h [see Fig. 6 of reference 1]. Then when the increase in wind-velocity sets in, the ratio suddenly decreases despite the continued increase in gradient. Evidently during the quiet hours of the summer night the electrode-effect is modified relatively little by factors associated with wind-velocity so that negative ions are more completely removed from the region near the surface. This correlation between wind-velocity and negative conductivity suggests that eddy-diffusion may play a dominant rôle here, increasing the negative conductivity near the surface during the day and causing a decrease in the ratio of positive to negative conductivity. However, there seems to be evidence that other meteorological factors must also be taken into account.

Since the wind-velocity in winter was small and comparatively constant day and night, turbulent stirring of the air was very weak. This was evidenced by the long time that light dry snow would remain poised on twigs, power-lines, etc. On this account the conductivity near the Earth's surface at College in winter, particularly the negative conductivity, may be expected to depend somewhat upon the gradient. Such a relation was shown in Figure 6 of the previous report [1]. This has been alluded to in a preceding paragraph as the "electrode-effect."

The theory of this effect and conclusions derived from it shall now be reviewed and compared with some interesting aspects of the data obtained at College.

THE ELECTRODE-EFFECT

Theory—Theoretical derivations of relations between various factors which determine the electrical state of the lower atmosphere have been made by Schweidler, Behacker, Swann, and Scholz. All these theories predict a concentration of positive space-charge in the first few meters of the atmosphere as one aspect of the so-called electrode-effect. Schweidler [11] was the first to publish a solution for the case of a non-turbulent atmosphere throughout which only small ions of a single mobility are produced at a uniform rate. The development was similar to that of J. J. Thomson [12] for the case of a uniform rate of ionization in a parallel plate condenser. After a better understanding was gained of the important rôle which nuclei of condensation (N) [large ions and uncharged particles] play in the destruction of small ions (n), Scholz [13] developed the theory for the case where nuclei are distributed uniformly with altitude and are so numerous that $(n/N) << 1$. This leads to quantitative expressions of the relations between the various elements and their dependence upon distance from the Earth. In Figure 5 some of these are shown graphically, several curves representing the relation between the ratio of the number of positive to the number of negative small ions and the potential-gradient for various assumed conditions as predicted from such theoretical considerations.

The symbols and abbreviations used in this discussion are generally the same as those used by Scholz, but for convenience these, together with additional relations, are listed here.

n_1 = number of positive small ions per cc
n_2 = number of negative small ions per cc
n_∞ = value of $n_1 = n_2$, for large values of x
N = number of nuclei per cc
k = average mobility of positive and negative small ions
α = coefficient of recombination between n_1 and n_2
η_1 = coefficient of combination between small and large ions
η_2 = coefficient of combination between small ions and uncharged nuclei
q = rate of formation of small ions per cc per sec
E = field-strength
i = vertical conduction-current
x = height (x_n = the height at which the conductivity was measured and x_E = that at which the gradient was measured)
e = electronic charge

$\beta = \eta_1/\eta_2$	$w = E/E_\infty$
$z = n_1/n_2$	$w_0 = E_0/E_\infty$
$\mu = (z-1)/(z+1)$	$a = \eta_1/4\pi e k$
$\xi = 2qx/i$	$a' = \alpha/8\pi e k$

The subscripts "$_0$" and "$_\infty$" are used to indicate values of the variables at the surface and at relatively great distances from the Earth, respectively. It should be noted that β is taken equal to 2 in the present discussion as well as that of Scholz.

Using Scholz's equation (22)

$$\mu = -\left\{1 + [1/(a-1)]w^a - [a/(a-1)]w\right\}^{1/2} \qquad (22)$$

the relation between z and w was determined for assumed values of a.

(Scholz's equations are referred to later in this paper by the numbers assigned by him.) Scholz showed that for $a=4$, his differential equation (24)

$$(dw/d\xi) = -2e/a\{1+[1/(a-1)]w^a-[a/(a-1)]w\}^{1/2} \qquad (24)$$

upon integration becomes his (27)

$$(e/\sqrt{2}) = \log_e\{[4+2w+\sqrt{6}(3+2w+w^2)^{1/2}]/(w-1)\}$$
$$-\log_e\{[4+2w_0+\sqrt{6}(3+2w_0+w_0{}^2)^{1/2}]/(w_0-1)\} \qquad (27)$$

Equation (24) is also readily integrable for $a=2$ and $a=3$. When $a=2$, the integrated form may be written

$$e\xi = \log_e[(w_0-1)/(w-1)]$$

and for $a=3$

$$[e\xi/(2/3)^{1/2}] = \log_e\{[5+w+2\sqrt{3}(w+2)^{1/2}]/(w-1)\}$$
$$-\log_e\{[5+w_0+2\sqrt{3}(w_0+2)^{1/2}]/(w_0-1)\}$$

As Scholz showed, w_0 is given by $w_0=a^{1/(a-1)}$. This has the values 2.00, 1.73, and 1.59 for $a=2$, 3, and 4, respectively. When $2q=\eta_1\eta_\infty N$, $i=2ekn_\infty E_\infty$ and $E_\infty=E\ w$, the expression $\xi=2qx\ i$ becomes $\xi=2\pi aNwx/E$. Thus either the variation of w with x or the variation of E with w at a given height may be found. The continuous curves in Figure 5 combine the relations between w and E with those between w and z. The values used for the parameters when evaluating the respective curves in Figure 5 are listed in Table 2.

TABLE 2—*Values of the quantities used in evaluating the relations between z and E shown in curves I to IX of Figure 5*

Curve	I	II	III	IV	V	VI	VII	VIII	IX
a or a'	2	3	4	3	3	3	3	1/3*	1/2*
N or n_∞	1000	1000	1000	4000	4000	4000	10000	2000*	2000*
x_n	100	100	100	100	100	150	100	100	100
x_E	100	100	100	100	50	50	100	100	100

*Values of a' and n_∞.

Curves I, II, and III show the effect of changing a when N and x are constant. It will be seen that if the ratio between η_1 and k is increased, the ratio of positive to negative conductivity is less for a given value of gradient. The effect of a variation in the concentration of nuclei may be seen by comparing curves II, IV, and VII for which N was taken as 1,000, 4,000, and 10,000, respectively, x and a remaining constant at 100 and 3, respectively. ($a=3$ if $k=1.5$ cm^2 volt^{-1} sec^{-1} and $\eta_1=8.1\times 10^{-6}$ cc sec^{-1}.) In this group it may be seen that for a given ordinate the abscissa is directly proportional to the number of nuclei. Such a comparison indicates that the low mean value of the ratio ($n_1\ n_2$) and the slight dependence of this ratio upon gradient, which is observed at certain land-stations, may in part be attributed to the large concentrations of nuclei at these stations. Eddy-diffusion would also tend to obliterate an electrode-effect or, in other words, that factor would tend to make the concentration of positive small ions more nearly equal to that of negative ions.

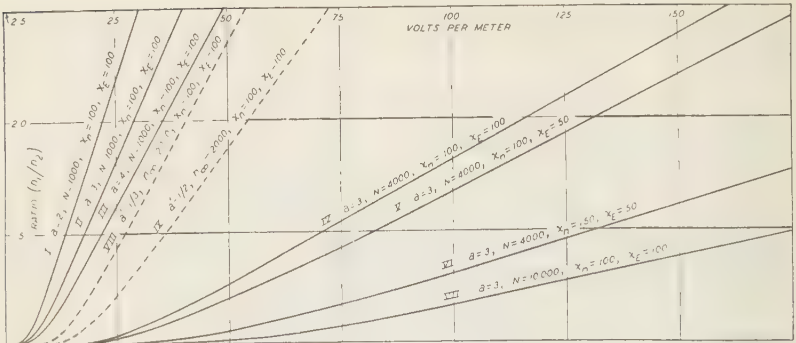


FIG 5—THEORETICAL RELATIONS BETWEEN RATIO OF NUMBER OF POSITIVE TO NEGATIVE SMALL IONS AND THE POTENTIAL-GRADIENT FOR QUIET AIR

Since the gradient was measured at a lower effective height than was the conductivity, the curves V and VI are included for comparison with IV. In order to obtain the relation between z and E under such conditions, a series of values of w was selected and the corresponding values of z, computed from (22), were assumed to apply at the point of measurement of the conductivity (x_n). Next corresponding values of w at the lower height (x_E), where the gradient was measured, were obtained from an equation of the form of (27). Using these latter values of w and the values of a, N, and x indicated, this same equation was next used to calculate E by making the substitution $E/w = E_x$. Whereas for curve IV the gradient and conductivity were considered to be measured at a height of 100 cm, in curve V, although the height of the conductivity-measurement is still taken as 100 cm, the height for the gradient is 50 cm. Curve VI is for the case where the conductivity is measured at the greater height of 150 cm and the gradient at the same height as for curve V, namely, 50 cm.

The broken curves VIII and IX apply when only small ions have to be considered. These curves were derived in a manner similar to that followed in deriving the other curves. For this case the relation between μ and w is

$$\mu = -\left\{1-[1/(1-a')]w^{2a'}+[a'/(1-a')]w^2\right\}^{1/2}$$

The differential equation involving E and w is

$$(\mathrm{d}w/\mathrm{d}\xi) = -(e/a'w)\left\{1-[1/(1-a')]w^{2a'}+[a'/(1-a')]w^2\right\}^{1/2}$$

In order to obtain the expression for the variation of w with ξ (or x), this equation was integrated directly for the values of $a' = 1/2$ and $1/3$ (values which correspond to $k = 0.88$ and 1.32 cm² volt⁻¹ sec⁻¹, respectively, when $\alpha = 1.6\times10^{-6}$ cc sec⁻¹ and $e = 4.8\times10^{-10}$ esu) instead of using a power series as was done by Schweidler. When $a' = 1/2$, the integrated form of the equation is

$$2e\xi = w_0 - w + \log_e[(w_0-1)/(w-1)]$$

and when $a' = 1/3$, it is

$$\sqrt{2}e\xi + K = [2(7-w^{2/3})(w^{2/3}+2)^{1/2}]/3 - 4(w^{2/3}+2)^{1/2} + (1/\sqrt{3})\log_e\left\{[(w^{2/3}+2)^{1/2}+\sqrt{3}]/[(w^{2/3}+2)^{1/2}-\sqrt{3})]\right\}$$

The constant of integration, K, in the latter, is expressed in terms of w_0, the value of w at $\xi=0$. In this case, $w_0=(a')^{1/2(a'-1)}$. For $a'=1/2$ or $1/3$, $w_0=2.00$ or 2.28, respectively. The variation of E with w is found by substituting $q=\alpha n^2$ and other quantities as before in $\xi=2qx/i$, giving $\xi=8\pi a' n_\infty wx/E$.

The theory developed by Scholz is applicable only when the concentration of nuclei is large compared with that for small ions. The curves of Figure 5 based on that theory approach the vertical axis as a limit as $N\rightarrow 0$, whereas the limit would actually be given by a curve such as VIII based on the small-ion theory. Further assumptions are involved than for the solid curves, but if the following values are assumed, $N=4{,}000$, $n_\infty=600$, and $\eta_1=5.3\times 10^{-6}$, then to be consistent with these q must equal 6.4.

Comparison of theory with observations—No reports of the results of any attempts to test this theory quantitatively have been found in the literature. The apparent lack of such attempts may perhaps in part be attributed to a generally held suspicion that such theories apply only for circumstances which are much simpler than the actual circumstances in nature—a suspicion which is obviously justified in many cases, for example, the summer season at College where, as has been noted, eddy-diffusion doubtless modifies the electrode-effect during the daytime. An attempt to derive expressions for the vertical distribution of gradient when eddy-diffusion is active was made by Whipple [14] for the restricted case that eddy-diffusivity and electrical conductivity are both independent of altitude. Recently a more general solution having only one of these restrictions, namely, that conductivity is independent of altitude, was found by Gish [reported to Amer. Geophys. Union at 21st annual meeting, 1940]. Although the latter is consistent with observations reported by Hogg [9] and may be applicable at a number of places where atmospheric-electric observations have been made, particularly at stations located in the outskirts of large cities, yet in its present state it can not be tested by the data obtained at College. Although some investigators in atmospheric electricity appear to discount the rôle of the electrode-effect, the comparison which follows, as well as the conspicuous dependence of (λ_1/λ_2) upon gradient in winter exhibited in the previous report [1], shows that important variations in λ_2 are to be regarded as manifestations of that effect.

The fact that the variations, both diurnal and interdiurnal, of the ratio (λ_1/λ_2) are so highly correlated with variations of the gradient in winter, when turbulent mixing is apparently quite small and constant, leads one to expect that the assumptions which underlie the theory of Scholz are approximately valid. In any case, a comparison of the values of that ratio in winter with corresponding values computed from the theory should give an indication of the extent to which the theory applies in this case. For this comparison the individual values of the ratio were arranged in 14 groups, according to the value of the gradient. The mean value of the ratio for each of these groups is charted as ordinate in Figure 6 against the mean value of gradient for the group as abscissa. A corresponding relation between the ratio (n_1/n_2), which is of course proportional to (λ_1/λ_2), and gradient derived from theory is represented by the broken line. This comparison shows that the parameters in the theoretical relation may be so adjusted that the latter will agree with the observations. However, in this case, the parameters were not deliberately adjusted for the purpose of effecting agreement between the

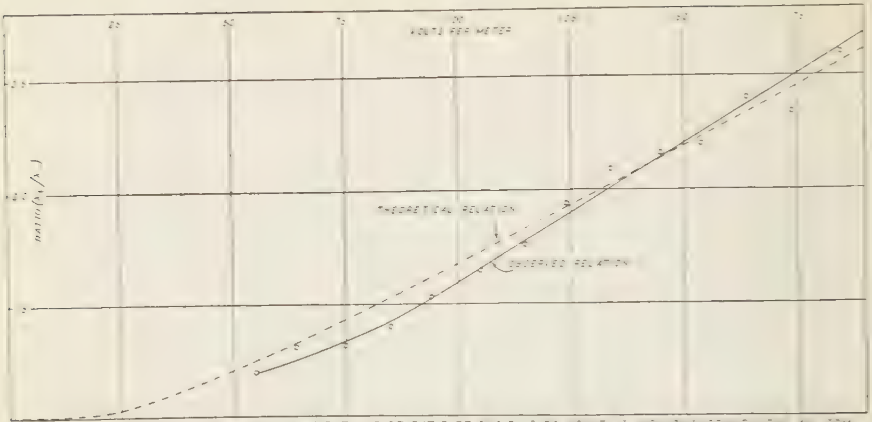


FIG. 6—AVERAGE VALUES OF POTENTIAL-GRADIENT AND OF RATIO OF [illegible] FOR ALL COMPLETE HOURLY VALUES, COLLEGE-FAIRBANKS (ALASKA) POLAR YEAR [illegible] TO FEBRUARY [illegible]

theoretical and the observed relation. The basis for the selection of parameters was rather as follows:

Attempts to measure the concentration of nuclei during the winter months at College were unsuccessful, but for the purposes of the present comparisons such data are needed. The value of 4,000 which was chosen as the value of N for curve V was the nearest even thousand to the mean derived from 112 observations made from March to August. The annual variation in positive conductivity suggests that the concentration of nuclei was approximately the same in winter as at the time when the latter were observed. The selection of $a = 3$ corresponds to the average mobility of 1.0 cm² volt^{-1} sec^{-1} calculated from simultaneous observations of conductivity and ion-number, and to a value of $8.6 \times 10^{-\text{[illegible]}}$ cc sec^{-1} for η_1. Some uncertainty exists regarding the height above the surface to which the measurements of gradient and conductivity apply. The values of potential-gradient were reduced to those measured by a collector placed one meter above the Earth's surface so they corresponded to the actual gradient at a height of not more than one-half meter. The intake to the conductivity-tubes was about 20 cm above and near the edge of the roof of the observatory which was approximately three meters above the surrounding ground. There is also involved in this comparison of the theoretical and the empirical relations the assumption that the mobility of positive ions is the same as that of negative ions. This was true for the mean of all values derived from simultaneous measurements of λ and n at College. However, the frequency-distribution of these different values of mobility contains the suggestion that the mean values may not be representative and that the mobility for negative ions may be significantly larger than that for positive ions. In that case the theoretical curve would fall below the one which represents the observations. The general effect of changes in the other parameters may be seen from an examination of the curves in Figure 5. It will also be seen there that the value (λ_+/λ_-) calculated by the theory for a given value of gradient depends on N and, since the individual

observations of N made from March to August showed considerable scatter from a minimum value of 300 to a maximum of 14,800 nuclei per cc, it seems that this may be an important factor in the considerable scatter which was manifested in the comparison of the individual hourly values of the ratio with those of gradient. For the mean values of the groups for the winter season, plotted in Figure 6, the residuals of these fluctuations appear to be small. Considering the uncertainty in several of the parameters, the agreement of the relation between $(\lambda_1\ \lambda_2)$ and gradient as derived from theory with that indicated by the observations seems to be close enough to warrant the conclusion that the theory of Scholz, with the slight modifications indicated above, approximately represents relations which occur in nature at certain times and places. It also seems that this theory deserves more attention than has been accorded to it in the past as an aid in the interpretation of some electrical aspects of the lower atmosphere. While this consideration of the electrode-effect provides an explanation of the variations in λ_2 which depart from those in λ_1, and thus disposes of that aspect, it does not appear to have any more direct bearing on the problem presented by the local diurnal variation of gradient and the diurnal variation in total conductivity at College. The theory does, however, contain the relations by means of which may be derived the diurnal variation in the concentration of nuclei and also that for the rate of production of small ions, which is consistent with the observed values of λ_1, λ_2, and gradient.

Diurnal variation in N and q—Values of N corresponding to the observed hourly values of $(\lambda_1\ \lambda_2)$ and those of gradient may obviously be obtained from curves such as V of Figure 5. Using these values of N and the observed values of conductivity, values of q may be obtained from the relation $4ekq=\eta_1\ (\lambda_1+\lambda_2)\ Nw$. Graphs for each set of values derived in this way appear in Figure 7. The minimum value of N occurs

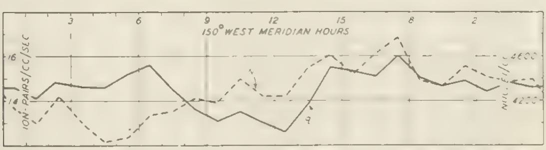


FIG. 7—CALCULATED VALUES OF NUCLEI (N) AND RATE OF PRODUCTION OF SMALL IONS (q) FOR ALL COMPLETE DAYS AT COLLEGE-FAIRBANKS (ALASKA) POLAR-YEAR STATION DURING WINTER (NOVEMBER 1932 TO FEBRUARY 1933)

at about 5^h, then follows a fairly steady rise to the maximum at about 17^h. The average decrease from the maximum to the minimum is more rapid after midnight. The period during which the nuclei appear to increase corresponds approximately with the period of activity at the College, beginning at about the time when the stoking of the fires of the heating and power-plant begin and continuing till the end of the daily classroom program. If the nuclei at the observing station come largely from the College, then the type of diurnal variation in N indicated by these calculations seems reasonable. From an examination of the graph for q it will be seen that according to these calculations an appreciable part of the diurnal variation in λ and gradient at College in winter must be assigned to a diurnal variation in q. The feature of most apparent significance here is the depression of q during the interval from about

8^h to 13^h. Since no satisfactory way of accounting for this as a real phenomenon has been found, one is inclined to regard it with reserve for the present. If some factor neglected in these calculations would have increased N between 8^h and 13^h by about 13 per cent at a maximum, then there would be apparently no significant diurnal variation in q. The principal maximum in N would then occur around midday. That would be more readily accounted for than is the depression in q. Although variations in q were invoked by Sheppard [15] to account for a correlation between measurements of wind-velocity and those of nearly all atmospheric-electric elements made at Fort Rae during the Second International Polar Year, the situation was very different at College, especially in winter, when during the day the average hourly wind-velocity did not vary from a mean of one meter sec by more than five per cent.

The results of this attempt to approach a specific quantitative account of the diurnal variation of conductivity and potential-gradient in winter at College, while in some respects not as conclusive as one would like, on the whole seem fairly satisfactory. It is obvious that had there been available suitable data for the diurnal variation in the concentration of nuclei and for the rate of formation of ions, not only would it have been possible to make a more conclusive test of the theory of the electrode-effect but apparently valuable information about some of the parameters might have been obtained.

References

[1] K. L. Sherman, Terr. Mag., **42**, 371-390 (1937).
[2] W. C. Parkinson and O. W. Torreson, C.-R., Assemblée de Stockholm, Union Géod. Géophys. Internat., Sec. Mag. Electr. Terr., Bull. No. 8, 340-345 (1931).
[3] F. J. Scrase, London, Met. Office, Geophys. Mem. No. 60 (1934).
[4] J. G. Brown, Terr. Mag., **40**, 413-424 (1935).
[5] O. H. Gish and K. L. Sherman, Nation. Geog. Soc., Contrib. Tech. Papers, Stratosphere Ser., No. 2, 94-116 (1936).
[6] W. J. Rooney and K. L. Sherman, Terr. Mag., **39**, 187-199 (1934).
[7] J. G. Brown, Terr. Mag., **38**, 161-173 (1933).
[8] J. J. Nolan and P. J. Nolan, Proc. R. Irish Acad., A, **43**, 79-93 (1937).
[9] A. R. Hogg, Canberra, Mem. Solar Obs., No. 7 (1939).
[10] C.-G. Rossby and R. B. Montgomery, Cambridge and Woods Hole, Papers Phys. Oceanogr. Met., **3**, No. 3 (1935).
[11] E. Schweidler, Wien, SitzBer. Ak. Wiss., IIa, **117**, 653-664 (1908).
[12] J. J. Thomson, Conduction of electricity through gases, 1st ed., 64-67 (1903), or 3rd ed., **1**, 193-196 (1928).
[13] J. Scholz, Wien, SitzBer. Ak. Wiss., IIa, **140**, 49-66 (1931).
[14] F. J. W. Whipple, Terr. Mag., **37**, 355-359 (1932).
[15] P. A. Sheppard, British Polar Year Expedition, Fort Rae, N W. Canada, 1932-33, **1**, 309-333 (1937).
[16] O. H. Gish, Nation. Res. Council, Physics of the Earth, **8**, Terrestrial magnetism and electricity, 149-230. New York, McGraw-Hill Book Co. (1939).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

TOTAL AND UNCHARGED NUCLEI AT WASHINGTON, D. C.

By K. L. Sherman

Abstract—Observations of the concentration of both uncharged and total condensation-nuclei were made at different times and places near Washington, using an Aitken nuclei-counter in conjunction with a cylindrical, electrical condenser through which air was drawn at a desired rate by a spring-driven turbine. The ratio (S) of the concentration of uncharged to that of all nuclei, serves as a measure of the relative magnitude of the coefficients of combination and those of attachment between small ions and charged and uncharged nuclei, respectively, provided the assumptions usually made in this connection are valid. Diverse values of S have been found heretofore when these were determined from the same data but by different methods. It is shown in the theory of least squares that the method of determining the best estimate of a quantity of this character depends upon the manner in which weights should be assigned to the data. It is shown here that the weight assigned to the observed number of particles falling on a square of the counter, should vary inversely as that number. The proper method of determining the best estimate of S, when weights are assigned in this manner, and also two other simpler methods were applied to these data. The surprisingly small differences in the three results, indicates these data are homogeneous.

From 620 individual samples of both uncharged and total nuclei, S was found to be 0.75 with a standard error of 0.02. This value of S is distinctly greater than that reported for other places but it is in close agreement with values previously determined at Washington with other equipment. No significant evidence of a dependence of S, upon time, upon place, or upon concentration of nuclei, such as some observers report, is provided by these data. An examination of the standard deviation of S for a single sample indicates that the variations which do appear are no greater than those which are to be expected from random errors. Systematic errors in all measurements of this sort may arise from the adsorption of nuclei on the walls of the apparatus. The differences in the values of S found at the different places may in part be attributed to this source. Four hundred individual samples taken, both before and after the air passed through the condenser with no field applied, indicate that 0.85 of the nuclei which enter this condenser get through. The procedure followed here was such that errors in the calculated value of S from this source are eliminated provided charged and uncharged nuclei are adsorbed with equal facility.

Introduction—The importance of condensation- (or Aitken-) nuclei in determining ionic equilibrium in the lower troposphere is now well established. Positive and negative small ions combine with charged nuclei or large ions and attach to uncharged nuclei, neutralizing the charge of the former and transforming the latter into large ions. Knowledge of both the absolute and relative magnitudes of the four coefficients of attachment and combination between small ions and nuclei is necessary for a complete understanding of the problem of ionic equilibrium. A comprehensive survey of those observations and experiments from which information concerning these coefficients could be obtained, was recently published [see 1 under "References" at end of paper]. The assumptions which are involved when the percentage of nuclei which are uncharged is used to indicate the relative magnitude of the coefficients of attachment and combination, have been discussed in detail elsewhere [1, 2]. Briefly, if it is assumed that the condensation-nuclei are made up of positively and negatively charged ions and uncharged nuclei ($N_a = N_1 + N_2 + N_0$) and that the rate of combination of small ions of one sign with large ions equals the rate of attachment of small ions of the other sign with uncharged nuclei, ($\eta_{12} n_1 N_2 = \eta_{20} n_2 N_0$ and $\eta_{21} n_2 N_1 = \eta_{10} n_1 N_0$), the relation $S = (N_0/N_a) = [1/(1 + \eta_{10} n_1/\eta_{21} n_2 + \eta_{20} n_2/\eta_{12} n_1)]$ results. From this it

may be seen that based on quite reasonable assumptions and upon observed or estimated values of the ratio n_1/n_2, observations of N_0 and N_a provide means of obtaining information regarding the ratio of the coefficients of attachment and combination, characteristic of uncharged and charged nuclei.

In this discussion n and N represent the number of small ions and nuclei, respectively, in one cc; η is designated the "coefficient of combination or of attachment" between n and N. Subscripts are applied to n, N, and η when it is necessary to make specific reference to them. The concentration of positive and negative small and large ions and uncharged nuclei is designated by the symbols n_1, n_2, N_1, N_2, and N_0, respectively. The attachment of n_1 to N_0 is referred to by the coefficient η_{10}, the combination of n_1 with N_2 by η_{12}; definitions of the other coefficients $(\eta_{0,1,2})$ may be inferred by comparison.

The results of two previous series of observations made at Washington from which the numbers of uncharged and total nuclei were determined have been published by Torreson and Wait [3]. A comparison of the results of four 24-hour series of observations of the total condensation-nuclei in March of the years 1927, 1928, and 1930 with the results of 16 complete days of record of large ions in March 1932, was made by Torreson [4]. In so far as the four series of observations of nuclei in the previous years could be taken to represent also the diurnal variation in nuclei for the 16 days in March, 1932, this comparison indicated a large variation in the ratio of the number of large ions and total nuclei, depending upon the time of day. This would imply that S also varies greatly during the day. The present series of observations was begun in order to obtain further information regarding S and its variations in and near Washington. The results are in agreement with those obtained from previous simultaneous observations of uncharged and total nuclei made here but they give no evidence of the diurnal variation in S suggested by Torreson [4].

Apparatus—The apparatus used was that designed by O. H. Gish for observation at sea, specifically for the National Geographic Society-University of Virginia Expedition which it was planned to send to the south-central region of the Pacific Ocean late in 1939, through the cooperation of the United States Coast Guard. It was hoped that the representative of the Department of Terrestrial Magnetism could make observations on board while traveling between islands occupied for magnetic stations. Some of the observations presented in this report were made during tests of the apparatus; the remainder were made after the expedition had been postponed because of the international crisis.

A photograph of the device used to remove the charged particles from the air to be sampled is shown in Figure 1. Air is drawn through the cylindrical electrical condenser (A) by the spring-driven turbine (B) which is similar to that used on the Ebert small-ion counter. The box (C) serves as a mounting for the condenser-system and contains the necessary batteries and a switch (D) for connecting the insulated central cylinder to either of the end-terminals of the batteries, one end-terminal of which is connected to the outer cylinder. A small sampling port (E) with a hinged door on the inside was constructed near the exhaust end of the cylinder. The hinged door is closed by a spring except when the

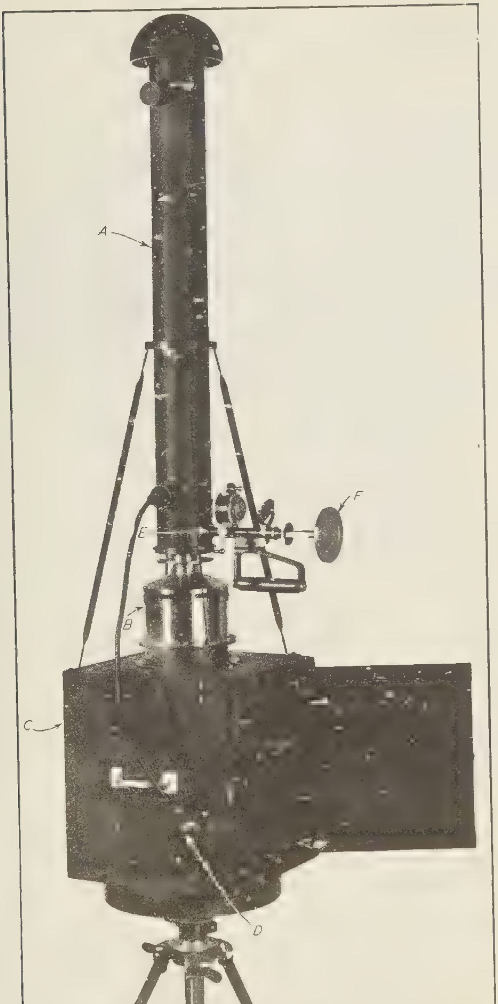


FIG. 1—APPARATUS TO DETERMINE TOTAL AND UNCHARGED CONDENSATION-NUCLEI IN THE ATMOSPHERE

nozzle of the counter is inserted for the sample. The latter automatically opens the door in such a way as to help deflect the air toward the nozzle-inlet. The tapered nozzle completely fills the sampling port so that air from the outside cannot enter and mix with the sample which is being taken inside the condenser.

The inner diameter of the outer cylinder is 7.3 cm. The outer

diameter of the inner cylinder is 5.7 cm. This cylinder is 61 cm long and has its ends plugged with brass discs. An indication of the lowest mobility of the ions removed can be obtained by considering that all ions with a mobility greater than $(\omega/4\pi CV)$ would be removed in passing through the condenser. The air-flow, ω, was decreased by a perforated disc placed in the intake-duct of the turbine so that approximately 100 cc per sec pass through the condenser. Using for C, 123 cm, the calculated capacitance of such a condenser, neglecting the end-effects, and for $V=270$ volts—the potential selected to be applied between the two cylinders—a value of 0.00024 $cm^2\ volt^{-1}sec^{-1}$ is indicated for the critical mobility.

The Aitken pocket nuclei-counter DTM No. 6 used for these observations is shown in position for obtaining a sample at F in Figure 1. The original intake-nozzle was replaced by a nozzle slightly longer, designed especially for use with the sampling port. The stirrer was not used in the counter during these observations. This accounts for the slight differences between the constants determined by Wait [5] and those used for the reduction of these observations.

Experimental procedure—The two types of information, which it was desired to obtain from the results, determined the sequence of sampling followed when making these observations. In addition to estimates of the relative number of uncharged nuclei, estimates were also desired of the portion of the nuclei lost by adsorption in passing through the condenser. The most obvious way of estimating the number of nuclei adsorbed in the condenser seemed to be to determine the concentration of nuclei before and after the air had passed through the condenser with no field applied. The number of particles counted on one square millimeter of the counting-stage will be indicated by m. If the sample was taken outside the condenser, m_q is used; m_o and m_p indicate that the sample was taken from within the condenser with the field on and off, respectively. If it is assumed that the observations, which are made to determine the portion absorbed, are related by the equation $m_p=mA_q$, an estimate of the proportion of nuclei adsorbed may be obtained from the parameter A.

No experiments were conducted which would indicate whether charged and uncharged nuclei were adsorbed in the same proportion. Until this is definitely known, there is uncertainty as to whether m_o should be compared with m_p or m_q when determining the ratio of uncharged to total nuclei. If the uncharged nuclei are not adsorbed in passing through the condenser, then when determining S, the samples giving m_o should be compared with those giving m_q, whereas if both uncharged and charged nuclei are adsorbed in the same proportion, m_o should be compared with m_p. Previously some observers have based values of S on comparisons of m_o and m_q. Although there may be theoretical grounds for expecting that slightly more charged than uncharged nuclei would be adsorbed, yet the difference should be small. Therefore the estimates of S made from these data are based on comparisons of m_o and m_p. These estimates of S would need to be revised if future work shows that charged and uncharged nuclei are not adsorbed in the same proportion.

In making these observations, samples giving m_o were always pre-

ceded and followed by samples giving m_p, and frequently also by samples giving m_q. A typical series consisted of: (1) Five individual samples of the air outside the condenser taken alternately with five samples after the air had passed through the condenser without the electrical field; (2) a series of ten samples taken after the air had passed through the condenser with the field applied; (3) five additional samples for both m_q and m_p taken alternately as under (1). Prior to March, 1940, forty such series were obtained which could be used for comparisons between m_p and both m_q and m_o. In addition 22 series of m_o and m_p only, were secured. Observations were made at several places in and about Washington, namely, in laboratory rooms of the Department of Terrestrial Magnetism, on the adjoining grounds, and in a wooded and sparsely settled locality in Virginia, 15 miles from Washington. Details of the first 62 series of observations are given in Table 1.

TABLE 1—*Uncharged and total condensation-nuclei at and near Washington, D. C., 1939*

Date	75° west meridian time	Number particles per square			k	Number nuclei per cc of air $\times 10^{-3}$			Location
		m_o	m_p	m_q		N_0	N_p	N_q	
1939	h m								
Aug. 29	22 00	7.0	8.7	11.1	1220	8.5	10.6	13.5	Room in laboratory at Department
	22 20	6.0	9.4	10.6		7.3	11.5	12.9	
31	15 20	5.8	10.8	12.9	1220	7.1	13.2	15.7	
	15 40	3.8	5.9	10.7		4.6	7.2	13.1	
	16 10	5.0	7.6	9.2		6.1	9.3	11.2	
Sep. 1	09 40	5.6	8.7	10.9	1220	6.8	10.6	13.3	
	10 00	9.0	11.3	14.3		11.0	13.8	17.4	
	10 20	7.5	12.2	11.1		9.2	14.9	13 5	
	10 40	7.4	12.9	12.5		9.0	15.7	15.2	
	11 00	9.0	15.5	15.5		11.0	18.9	18.9	
	11 20	10.2	16.2			12.4	19.8		
Sep. 2	05 55	3 4	7.5	7.8	1220	4.1	9.2	9 5	
	06 20	3.5	6 5	6.8		4.3	7.9	8.3	
	06 45	5.6	9.9	10.1		6.8	12.1	12.3	
	07 05	6.6	7.1	10.7		8.1	8.7	13.1	
	07 35	6.3	10.6			7.7	12.9		
	07 45	8.9	11.7			10.9	14.3		
	07 55	9.8	13.7			12.0	16.7		
	12 40	5.1	8.6	10.8	2200	11.2	18.9	23.8	
	12 55	5.8	7.1	8.5		12.8	15.6	18.7	
Sep. 4	10 40	14.7	17.8		2200	32.3	39.2		Outside, on grounds of Department
	11 05	14.1	15.7	21.9		31.0	34.5	48.2	
	11 45	9.9	14.1	19.1		21.8	31.0	42.0	
	12 05	13.9	16.6	21.3		30.6	36.5	46.9	
	12 25	14.5	14.5			31 9	31.9		
Sep. 5	09 35	7.2	7.7	10.8	2200	15.8	16.9	23.8	
	09 55	7 4	9 7	10.8		16 3	21 3	23.8	
	10 20	9.4	12.2	13.3		20.7	26.8	29.3	
	11 10	9.1	13.3	14.5		20.0	29.3	31.9	
	11 40	10.5	12.0			23.1	26.4		
	11 55	7.4	12.5			16.3	27.5		
	12 05	8.4	9.6			18.5	21.1		
Sep. 6	06 20	9.2	12.3		2200	20.2	27.1		
	06 35	6.8	10.8			15.0	23.8		
	06 50	8.4	13.3			18.5	29.3		
	07 25	15.3	16.6	19.6		33.7	36.5	43.1	
	07 45	12.5	14.4			27.5	31.7		

Table 1—*Uncharged and total condensation-nuclei at and near Washington, D. C., 1939* Concluded

Date	75° west meridian time	Number particles per square			k	Number nuclei per cc of air $\times 10^{-3}$			Location
		m_0	m_p	m_q		N_0	N_p	N_q	
1939	*h* *m*								
Oct. 6	10 10	5.5	9.0		680	3.7	6.1		In wooded region of Virginia
	10 45	7.1	7.4	9.4		4.8	5.0	6.4	
	11 10	6.7	8.8	9.7		4.6	6.0	6.6	
	12 10	5.2	9.3	10.2		3.5	6.3	6.9	
	12 30	10.9	13.5			7.4	9.2		
	13 50	5.8	10.2	11.0		3.9	6.9	7.5	
	14 35	5.5	8.4			3.7	5.7		
	14 50	5.9	7.2			4.0	4.9		
	15 05	5.6	8.0			3.8	5.4		
	15 25	6.2	7.9			4.2	5.4		
	15 55	6.1	8.1			4.1	5.5		
	16 45	7.1	10.9			4.8	7.4		
	17 00	9.0	10.0			6.1	6.8		
Oct. 11	14 10	12.4	12.8	14.8	2200	27.3	28.2	32.6	Under shelter on grounds of Department
	14 35	7.8	11.3	13.7		17.2	24.9	30.1	
	15 00	9.6	14.3	15.2		21.1	31.5	33.4	
	15 30	10.4	14.4	15.8		22.9	31.7	34.8	
Oct. 12	15 00	6.3	10.3	9.0		13.9	22.7	19.8	
	15 25	11.4	13.2	13.6		25.1	29.0	29.9	
	15 50	11.3	12.1	14.7		24.9	26.6	32.3	
	16 15	9.8	8.9	11.8		21.6	19.6	26.0	
Oct. 19	14 25	5.8	9.4	13.7		12.8	20.7	30.1	
	14 40	6.5	5.0	8.4		14.3	11.0	18.5	
	14 55	9.1	8.1	8.8		20.0	17.8	19.4	
	15 10	6.3	6.7	9.0		13.9	14.7	19.8	
Mean of 62		8.1	10.8	......	......	......	......	......	
Mean of 40		......	10.4	12.3	......	......	......	......	

Methods of analysis—A uniform method for estimating either the proportion of nuclei adsorbed in the apparatus or the proportion which are uncharged has not as yet been adopted by the different experimenters. The importance of the method followed in the computation of the results is well illustrated by examples which have appeared in the literature. For example, J. J. Nolan and P. J. Nolan obtained 1.92 as the ratio $(1/S)$ at Glencree [6]. This is the mean value of 235 individually calculated ratios. A value of $1/S=1.55$ based on the same data would be inferred from Israël's value of 3.64 for $R=[2\ (N_a/N_0-1)]$, a measure of the relative proportion of uncharged and charged nuclei of either sign. Israël took the mean of the 235 individually calculated values of R [7].

If such widely differing estimates of S can be obtained from the same set of data depending on the method of calculation, it seems highly desirable to determine how the data should be reduced in order to obtain the best estimate. Obviously, from a given series of data, only one estimate of S will represent the physical relationship between N_0 and N_a from which the relative magnitude of the combination- and attachment-coefficients can be inferred. This estimate of S should be mutually

consistent with other estimates, such as R, derived from the same data. Likewise there is but one correct estimate of the percentage of nuclei adsorbed in the apparatus, obtainable from a given series of data. From the standpoint of a problem in least squares, the values of the parameters can be properly determined only when it is known how weights should be assigned to the observed quantities. Furthermore each procedure, which may be used in computing the parameters, automatically applies weights in a manner characteristic of that procedure. Although the manner of applying weights which is characteristic of Israël's method of computation of R is not apparent, some of the results of simple forms of weighting will be given as examples. Assume that it is desired to obtain the slope of a line relating two variables when it is known that the line passes through the origin. In other words, the parameter b is required in the relation $y=bx$. Then it may be shown [8] that if the y-coordinates are subject to error but x is free of error, $b=(\Sigma wxy/\Sigma wx^2)$, where w denotes the weight assigned to y and Σ indicates the summation of the terms. From this it follows that if $w=(1/x)$, $b=(\Sigma y/\Sigma x)$ and if $w=(1/x^2)$, $b=[\Sigma(y/x)/h]$, h being the number of terms. If only the x-coordinates are subject to error, $b=(\Sigma wy^2/\Sigma wxy)$, w in this case being the weight assigned to x.

It will be recognized that if N_a is substituted for y and N_0 for x, the value obtained for b from the expression $b=[\Sigma(y/x)/h]$ corresponds to that which was obtained for $(1/S)$ by the Nolans and others. It is therefore pertinent to ask whether the assumptions made in determining this expression are tenable when used for computing $(1/S)$. Are only the values of N_a subject to error and should they be weighted as $(1/N_0^2)$? It is obvious at once that both N_a and N_0 are subject to error and in much the same way, and therefore they should each be given similar weights. As to how that weight should vary with either of them is not obvious. An attempt will be made to clarify this problem in the next section.

Determination of the weight—The weight of a function is by definition [8] inversely proportional to its variance σ^2. Thus, before weights can be assigned, the variance must be estimated. There are several ways to obtain estimates of the variance of the counts of nuclei-concentrations and of the way this variance varies with the concentration. Scrase showed [9] that based on random errors of sampling alone, the number of nuclei falling on a square of an Aitken counter should conform to a Poisson distribution and that σ^2 for a single sample would therefore be equal to the average number falling. He compared the distribution actually observed with his counter with the theoretical distribution and found good agreement. A similar comparison was made using DTM counter No. 6. The custom followed in the Department of Terrestrial Magnetism is to base an estimate of nuclei-content on the mean of a series of ten samples of air. Two groups of 20 series each were selected, the first group in which approximately ten, and the second, in which approximately fifteen, nuclei fell per sample. The mean values of m in the individual series in the first group are from 9.1 to 11.3 with a group-mean of 10.0 for the 200 samples. The range of m in the individual means from ten samples in the second group ranged from 13.4 to 17.6, with a group-mean of 15.0 for the 200 samples. The calculated variance

of the first group is $\sigma^2=8.3$ whereas Scrase's theoretical value would be 10.0. For the second group $\sigma^2=12.9$ instead of 15.0. Thus the variance determined in this way is about 18 per cent less than the theoretical value. However both the theoretical and observed variances show that the variance is proportional to m and so it seems reasonable to conclude that the weight of m should be assigned inversely proportional to m.

A χ-square test indicates that the observed points are fitted very well by either the Poisson or normal distribution-curves. The agreement with the Poisson distribution indicates that for some purposes the theoretical value should be quite useful. The similarity between the observed and the normal distribution based on it is taken to indicate that for many statistical considerations based on the normal law, observations of m may be considered to be distributed normally.

It seems desirable to emphasize a point stated by Scrase, namely, that the theoretical value of σ^2 is based on random errors of sampling alone. Other variable errors, for example, errors of counting and errors in setting for the sample, would be expected to influence the variance deduced from the observations. It should be mentioned also that observations with a single counter can give no indication of constant errors which may be present.

It is customary for observers to express the results of their observations in terms of the number of nuclei per cc and to estimate S and A from these quantities. In the case of an Aitken counter a formula $N=km$ is used to calculate N from m where k is a constant characteristic of the instrument and of the volume of the sample admitted to the counter. It is evident that when the calculated values of N_0 and N_a are used for estimating S, the observed quantities, m, have in effect already been weighted by the factor k. In practice k tends to increase with increase in N. That is, when N increases, the size of the sample taken is usually decreased in steps differing by about a factor of two so as to keep m within a range which can be counted. In so far as k is proportional to N, if these values of N are used in determining S and A, the weight of N should vary inversely as N^2. This shows what justification there is for weighting the points as $(1/N^2)$, a question raised in the previous section. However, no justification is found for considering that only one of the variables is subject to error. From the foregoing it may be seen that it is easier to assign the correct weights when computing S and A if the observed quantities (m) are used rather than the derived values (N).

Calculation of parameters—The least-squares solution based on the method of weighting required in this problem reduces to a convenient form for computation. Considering again the equation of the form $y=bx$, b may be obtained [8] from $b^2-[(\Sigma wy^2/\Sigma wxy)-(\Sigma wx^2/c\Sigma wxy)]b-(1/c)=0$. Here w is the weight assigned the values of x, and c is the ratio of the weight of y to that of x. It should be noted that w is permitted to vary from point to point but the ratio c is assumed to be the same for each point. For the parameters which it is desired to calculate from these data, observed quantities m_y and m_x are to be compared and therefore they replace y and x, respectively, in the above expression. It was shown in the previous section that the weight assigned to m should vary inversely as that quantity. For w and c, the expressions $[1/(m_x+m_y)]$

and $(\bar{m}_x/\bar{m}_y)$ should therefore be substituted, respectively, where $\bar{m}_x$ and $\bar{m}_y$ refer to the mean values of those quantities. The subscripts x and y depend on the parameters being calculated. For example, in the calculation of S from the above expression, S, m_o and m_p should be substituted for b, y, and x, respectively. For the weight factors w and c, the expressions $[1/(m_o+m_p)]$ and $(\bar{m}_p/\bar{m}_o)$, are substituted. Following this method, the first 62 series of observations of m_o and m_p obtained on eleven days prior to March, 1940, gave a value of 0.75 for S.

Similarly when A is calculated, A, m_p and m_q would correspond to b, y, and x, respectively. The weight of m_q would be $[1/(m_p+m_q)]$ and $c=(\bar{m}_q/\bar{m}_p)$. Forty series of observations of m_p and m_q prior to March, 1940, gave a value of 0.85 for A.

Two other similar parameters, calculated from 71 of the series of m_p and m_q which were suitable for this purpose, are of interest. In the first case the value of m from the first, third, fifth, seventh, and ninth samples in a series was substituted for y and the value of m for the remaining five samples was substituted for x. In this case, b is designated by E. In the second case, the value of m from the first five samples in a series was substituted for y and the value from the last five samples, was substituted for x. In this case b is designated by F. The values of E and F, calculated by different methods, are of interest because it is known that the true value of both of these parameters is unity and so their calculated value should approach unity if a great number of samples is used for the determination. Values of S, A, E, and F were obtained by three different methods. In method 1, the values were calculated using the weighting and method outlined above. Using method 2, the value of these parameters was calculated from a formula of the form $b=(\Sigma y/\Sigma x)$. The weighting corresponding to this formula was discussed above and is of a form tentatively recommended [1]—if all observations were made with the same volume of sample—for calculation of the parameters, until the correct method of weighting is known. By the third method the values were calculated from a formula, $b=[\Sigma(y/x)/h]$, also discussed in a previous section, and corresponding to the method used by the Nolans [6] for calculating $(1-S)$ and by Torreson and Wait [3] for calculating A and S. The results of these computations are summarized in Table 2 for comparison. H is the number of individual samples of both m_x and m_y upon which the determination was based.

TABLE 2—*Summary of observations and of computed statistics of number of uncharged and total nuclei at Washington, D. C., 1939-40*

Parameter	Mean value of observed number		H	Method			δ_b	σ_b
	m_y	m_x		1	2	3		
A	10.4	12.3	400	0.846	0.846	0.850	0.020	0.39
S	8.1	10.8	620	0.748	0.751	0.753	0.021	0.51
E	11.7	11.5	355	1.018	1.015	1.018	0.018	0.34
F	11.6	11.6	355	1.002	1.001	1.024	0.026	0.49
S_t	15.5	20.3	100	0.764	0.764	0.762	0.032	....
S_f	19.2	24.1	100	0.830	0.796	0.811	0.045	....

The standard error of b, corresponding to the third method, was calculated in the usual way and is given for each of the parameters under δ_b in Table 2. It will be recognized that none of the estimates of E and F differ from unity by more than δ_b. In no case is the overall difference between the values obtained by the three methods of computing greater than δ_b. The differences are so small as to make the method of computation optional for these data. The weighting will not be important if the data are so homogeneous that there is no tendency for the different observed quantities m_y and m_x to indicate different values for the parameters. To illustrate, consider a simple case in which all the observed points lie on a straight line through the origin. It is obvious that then it is not necessary to consider whether the weighting varies with m or not.

In the case of the Glencree data, the weighting has an important effect upon the mean value calculated for S, if the derived values N_0 and N_a are used in the computation. From the 235 series of observations, the original calculation [6] gave $(1\ S)=[\Sigma(N_a\ N_0)\ h]=1.92$, or $S=0.52$. From the same data, Torreson and Wait [3] calculated $S=0.56$, using the formula $S=[\Sigma(N_0\ N_a)\ h]$. It was shown above that use of the latter formula tacitly assumes that all the error is in N_0 and that the points are weighted as $(1\ N_a^2)$. If instead it is assumed that all the error is in N_0 but that the points are weighted as $(1\ N_a)$, the formula $S=(\Sigma N_0\ \Sigma N_a)$, gives 0.64 for S. The large differences in S obtained from these data, depending on the method of computation or weighting, result from the tendency of S to be higher when the nuclei-concentration is great. It would be interesting to utilize the observed quantities m for comparisons between the three methods used in this article. It is hoped that in the future observers will publish these observed quantities or details of the instrument and sampling constants, or preferably both these items, along with the derived values N_0 and N_a.

Variation in S and A—Variations in S and A are of nearly as much interest as their absolute values. If the neutral particles and large ions are the same size, because of the added attraction of the charge on the large ions, small ions should combine more readily with the oppositely charged large ions than with the neutral particles. From discussions by Whipple [10] and Harper [11] of the difference between the coefficients of attachment and combination, it is evident that the exact quantitative relationships are still in doubt. However, it appears that for small nuclei the difference may be quite large.

On the basis of Wright's modification [12] of Whipple's theory, Torreson showed [13] that large variations would be required in both the relative and absolute magnitudes of the combination- and attachment-coefficients if these factors alone were to account for the observed relationship between air-conductivity and nuclei-content at Huancayo, Peru.

Variations in the combination- and attachment-coefficients have been assumed in several other instances, in order to bring various atmospheric-electric elements into agreement. However, there is little direct experimental evidence to support such assumptions and usually the lack of agreement may be attributed to other factors.

One of the first conclusions that may be drawn from these data is that these samples of air indicate that large variations in the relative number of uncharged nuclei did not generally occur. Although rather

large variations appear in the individual points, these variations are no greater than found when comparing data which contain only similar random errors. Therefore it is concluded that variations in S and A may be largely attributed to random errors in the observations. Variations in the observations were measured by the standard deviations of S, A, E, and F for a pair of individual samples. These standard deviations, σ_S, σ_A, σ_E, and σ_F, respectively, were based on computations made by using method 3 and are tabulated under σ_3 in Table 2. Alternate individual samples were used when computing E, hence σ_E is a measure of the scatter in samples taken at the same time and place. Although statistical tests may be interpreted to indicate that σ_S and σ_A are significantly greater than σ_E, the differences do not necessarily indicate actual changes in the ratio of the combination- and attachment-coefficients in the case of S or actual changes in the percentage of nuclei adsorbed within the condenser in the case of A, for reasons which follow.

In the case of A, the deviations might be caused by actual, but perhaps random, differences in the nuclei-content at the point of sampling, remembering that the sample for m_6 is taken outside the condenser whereas that for m_7 is taken inside. Three factors which may be expected to cause variations in S will be considered: (a) The assumptions made in deriving the equation for S are not valid; this subject has been discussed in detail elsewhere [2] and nothing further can be added as a result of this analysis. (b) The ratio (n_1/n_2) is not constant; simultaneous observations were not made of (n_1/n_2) so its variations are not known, but it is well known that it is subject to variations. Although S is not sensitive to small changes in this ratio, provided the ratios are nearly their normal value, S approaches zero [2] for either large or small values of (n_1/n_2) and therefore changes in the ratio might be expected to produce a larger value of σ_S than that found for σ_E. (c) Actual changes in the nuclei-content which occurred between the time the samples for m_7 and m_6 were taken, would cause variations in S. Five of the samples for m_7 preceded and five followed the samples taken for m_6 in order to partly eliminate that part of the changes which progressed linearly with time; however, the effect of random changes remained. The likelihood of these causing variations in S may be tested by comparing the standard deviations of E, F, and S. Identical observations were used in computing E and F so that differences in their standard deviations are attributed to differences in time of sampling of the groups of observations being compared. There was approximately the same average difference in time between taking the samples for the first five and last five counts from which comparison F was computed as there was between the samples of m_6 and m_7 from which S was obtained. It will be noted that σ_F is nearly as much greater than σ_E as is σ_S, indicating that the difference in time of sampling may account for practically all the difference between σ_E and σ_S also.

If none of the difference between σ_S and σ_E is attributed to this cause, a difference this great would be expected if half the samples upon which the estimate of S was based had been taken from a population having a mean value of $(0.75+0.12)$ and the mean value of the other half had been $(0.75-0.12)$. Thus even based on the untenable assump-

tion that all the difference between σ_S and σ_E arises from real differences in S its variations are much smaller than has often been assumed.

In addition to such statistical tests, the data were grouped in various ways in order to determine if more detailed examination would reveal important variations in S. Only one grouping—the 20 series of observations taken in the laboratory room—yielded a value of S whose departure from the mean might be considered to be significant. The value of 0.65 derived from this grouping is separated from the mean of all by approximately twice the standard error of the difference.

Values calculated from the observations made at other locations are not significantly different, nor do these data give any indication of variations of S with nuclei-number. Grouping according to time of day will be discussed in the next section.

Observations during March, 1940— Although the samples of air which had been taken at different times and places did not indicate deviations in S greater than were to be expected because of experimental errors, a few observations were made in the early morning for comparison with daytime values, in order to determine whether larger variations would be found in S, particularly to determine whether S undergoes a marked diurnal variation at Washington as suggested by Torreson [4]. The observed values of m_o and m_p from five series obtained between 03^h and 05^h on March 16 and again on March 17, are given in Table 3. Ten addi-

Table 3—*Uncharged and total condensation-nuclei on the grounds of the Department of Terrestrial Magnetism, Washington, D. C., March, 1940*

Day	75° west meridian time		Early-morning observations: Number particles per square m_o	m_p	Number nuclei per cc $\times 10^{-3}$ N_o	N_p	Day	75° west meridian time		Daytime observations: Number particles per square m_o	m_p	Number nuclei per cc $\times 10^{-3}$ N_o	N_p
1940	*h*	*m*					*1940*	*h*	*m*				
Mar. 16	3	35	15.1	17.2	33.2	37.8	Mar. 15	15	30	22.9	22.2	50.4	48.8
		55	9.7	15.0	21.3	33.0			45	23.0	34.5	50.6	75.9
	4	20	12.9	15.2	28.4	33.4		16	05	22.7	25.9	49.9	56.9
		50	11.9	15.1	26.2	33.2	16	11	05	19.9	25.6	43.8	56.3
	5	05	11.5	16.1	25.3	35.4			25	16.9	27.5	37.2	60.5
17	3	30	12.9	17.4	28.4	38.1		15	15	16.6	23.8	36.5	52.4
		45	14.3	23.4	31.5	51.5			30	15.9	18.4	35.0	40.5
	4	05	22.9	28.0	50.4	61.6	17	14	50	15.3	20.0	33.7	44.0
		25	25.7	28.5	56.5	62.7		15	10	20.3	19.7	44.7	43.3
		45	18.4	27.5	40.5	60.5			25	18.2	23.1	40.0	51.0
Means			15.5	20.3	34.2	44.7	Means			19.2	24.1	42.2	53.0

tional series taken for comparison on adjoining days are also given. Since the observations on the individual days did not indicate significant differences, the ten early-morning and ten daytime values have been summarized together in Tables 2 and 3. The value of S obtained from the ten early-morning observations is designated S_t and that obtained from the ten additional series during the day is designated S_j. From an exam-

ination of the standard errors of the determinations it will be noted that S_t and S_j are not significantly different from each other or from the value of S obtained from the 62 previous series. Since neither the value of S from these observations nor that from the previous series obtained in the laboratory early in the morning show any evidence of significant differences from daytime values, it is concluded that the previous indication of a large diurnal variation in S at Washington was probably caused by lack of simultaneous observations.

Discussion—If it is assumed that $N_1 = N_2$ and that $(\eta_2/\eta_1) = (\eta_{22}/\eta_{12})$, estimates of the relative magnitude of the combination- and attachment-coefficients may be made from the estimate of S and from the expression derived for it. Upon making these assumptions the expression for S reduces to $S = [1/(1+2\eta_1/\eta_{12})]$. According to this expression if S is taken to be 0.75, the ratio $(\eta_{12}/\eta_1) = 6$. This indicates that a small ion attaches to a charged nucleus much more readily than with an uncharged one. Although as indicated previously this value is rather larger than has been indicated by some other observations, it cannot at present be ruled out on theoretical grounds alone.

The large value of S and its constancy are considered the two points of primary interest. That the value of S as deduced from measurements of m_o and m_p is greater at Washington than at any place from which measurements have been reported may be seen from an examination of Table 2 of a previous paper [1]. However, the results of this series of measurements are in agreement with those made in 1931 by Torreson and Wait [3] using a large-ion counter for removing the charged nuclei. From 21 series of observations of m_o and m_p, obtained on six days during July and August, they found a value of 0.72 for S calculated by the third method which differs from the present value of 0.75 by approximately the standard error of the difference. From 36 series of observations of m_o and m_q, obtained on eight days in October and November, they obtained a value of 0.72 for $A \times S$. If their value of 0.92 based on 18 series of observations of m_p and m_q is used for A, 0.78 is deduced for S, again differing from the present value by approximately the standard error of the difference.

If a value of $A \times S$ be used for the ratio (N_0/N_a), which would be the correct method if only charged nuclei are adsorbed in the condenser, somewhat better agreement would be found between the present series of observations and those made elsewhere. It would be interesting to know whether this is the source of the comparatively higher value found at Washington.

Another possible source of a constant error in the determination of S is associated with the instrument and size of sample. Using a single nuclei-counter, samples of the same size should always be taken for comparisons of the uncharged and total nuclei, otherwise the value of S would include any constant error in the ratio of the two values of k—the instrument-factors corresponding to samples of the two sizes. If two instruments are used, the observational procedure should be designed so that S will not contain a constant error arising from differences in the two instruments.

Before too much reliance is placed on the differences in S as reported at different places, it seems necessary to consider differences in

the instruments, in the observational procedure, and in the method of analysis used. It would be much more satisfactory could these three factors be standardized.

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References

[1] O. H. Gish and K. L. Sherman, Trans. Washington Meeting, September 1939; Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11 (In press).
[2] O. H. Gish, Nation. Res. Council, Physics of the Earth, **8**, Terrestrial Magnetism and Electricity, 149-230. New York, McGraw-Hill Book Co. (1939).
[3] O. W. Torreson and G. R. Wait, Terr. Mag., **39**, 47-64 (1934).
[4] O. W. Torreson, Terr. Mag., **39**, 65-68 (1934).
[5] G. R. Wait, Beitr. Geophysik, **37**, 429-439 (1932).
[6] J. J. Nolan and P. J. Nolan, Proc. R. Irish Acad., A, **40**, 11-59 (1931).
[7] H. Israël, Beitr. Geophysik, **40**, 29-43 (1933).
[8] W. E. Deming, Some notes on least squares. Washington, D. C., Graduate School, Dept. Agric. (1938).
[9] F. J. Scrase, Q. J. R. Met. Soc., **61**, 367-379 (1935).
[10] F. J. W. Whipple, Proc. Phys. Soc., **45**, 367-380 (1933).
[11] W. R. Harper, Phil. Mag., **18**, 97-113 (1934); **20**, 740 (1935)
[12] H. L. Wright, Proc. Phys. Soc., **48**, 675-689 (1936).
[13] O. W. Torreson, Terr. Mag., **44**, 59-74 (1939).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE VERTICAL DISTRIBUTION OF IONIZATION IN THE UPPER ATMOSPHERE

By C. L. Pekeris

Abstract—Some transformations are given of the de Groot-Appleton formula to facilitate its use for determining the distribution of ionization with height from equivalent-height data. The method is applied to data published by Appleton for noon conditions in England in April and May, 1933, and the results are shown in Figures 2, 3, and 4. The scale-height in the F_2-layer on these days was of the order of 20 to 30 km. In the last section, a formula is derived for determining the vertical distribution of electron-collision frequency from simultaneous measurements of the reflection-coefficient as a function of frequency.

§ 1. The quantity that is determined directly by ionospheric soundings at vertical incidence is the equivalent path P', which is given by [see 1 of "References" at end of paper]

$$P'=c\int\frac{\mathrm{d}s}{U} \tag{1}$$

where c is the velocity of light and U is the group-velocity for the given frequency f of the wave. Since (c/U) is less than unity, P' is greater than the actual path $2h$ traversed by the ray; h is however greater than half the optical path P, which is given by

$$P=\int\mu\mathrm{d}s=\frac{1}{f}\int_0^f P'(f)\mathrm{d}f \tag{2}$$

μ being the real part of the refractive index. U and μ are connected by the relation

$$\frac{c}{U}=\frac{\mathrm{d}}{\mathrm{d}f}(f\mu) \tag{3}$$

μ is in general a complicated function of the ionization-density N, the electron-collision frequency ν, the intensity of the Earth's magnetic field and of f. For the ordinary ray we may, as a first approximation, neglect the influence of the Earth's magnetic field, whereby μ is given by [2]

$$\mu^2=1-f_0^2/f^2 \tag{4}$$

with $f_0^2=Ne^2/\pi m$; (4) is correct to second order terms in (ν/f). To the same order of approximation the absorption-coefficient k is given by

$$k=\frac{\nu}{2c}\left(\frac{1}{\mu}-\mu\right)=\frac{\nu f_0^2}{2cf\sqrt{f^2-f_0^2}} \tag{5}$$

Now, with the expression for μ given in (4) we obtain from (3) and (1)

$$P'(f)=\int\frac{\mathrm{d}zf}{\sqrt{f^2-f_0^2}}=2\int_0^h\frac{\mathrm{d}zf}{\sqrt{f^2-f_0^2}}=2h'+2\int_0^{y_0}\frac{\mathrm{d}zf}{\sqrt{f^2-f_0^2}} \tag{6}$$

where h denotes the maximum height reached by the wave, h' the height below which f_0 vanishes, and $y_0=(h-h')$. In the integral in (6), f_0 is a function of z, or z a function of f_0 and we may therefore write

$$\phi(f) \equiv P'(f) - 2h' = 2\int_0^f \frac{G(f_0) f \mathrm{d}f_0}{\sqrt{f^2 - f_0^2}} \tag{7}$$

where

$$G(f_0) = \mathrm{d}z/\mathrm{d}f_0 \tag{8}$$

It was noticed by de Groot [3] that (7) is an Abelian integral equation, whose solution, under certain restrictive conditions, which we shall discuss later, is

$$G(f_0) = \frac{1}{\pi} \frac{\mathrm{d}}{\mathrm{d}f_0} \int_0^{f_0} \frac{\phi(f)\mathrm{d}f}{\sqrt{f_0^2 - f^2}} = \frac{\mathrm{d}z}{\mathrm{d}f_0} \tag{9}$$

If the equivalent path is measured for all frequencies below a certain value f_0, then the height at which ionization corresponding to f_0 prevails can be determined by quadratures from (9). It is seen from (9) that generally the major contribution to the integral arises from values of f which are close to f_0, so that uncertainties in $\phi(f)$ for values of the argument which are not in the neighborhood of f_0 do not affect markedly the value of the integral. On account of this circumstance the error introduced by extrapolating the observed $P'(f)$ to zero-frequency diminishes with increasing values of f_0. Furthermore, for higher frequencies formula (4) applies with increasing accuracy. Integrating (9) with respect to f_0 we obtain

$$z = h' + \frac{1}{\pi} \int_0^{f_0} \frac{\phi(f)\mathrm{d}f}{\sqrt{f_0^2 - f^2}} \tag{10}$$

a relation between f_0 and z derived by Appleton [4].

§ 2. For the numerical application of (10) it is convenient to introduce the variable

$$u = \cos^{-1}(f/f_0) \tag{11}$$

whereby (10) transforms into

$$z = h' + \frac{1}{\pi}\int_0^{\pi/2} \phi(f)\mathrm{d}u = h' + \frac{1}{\pi}\phi(f)u\Big|_0^{\pi/2} - \frac{1}{\pi}\int u\mathrm{d}\phi = h' + \frac{1}{\pi}\int_0^{\phi(f_0)} u\mathrm{d}\phi \tag{12}$$

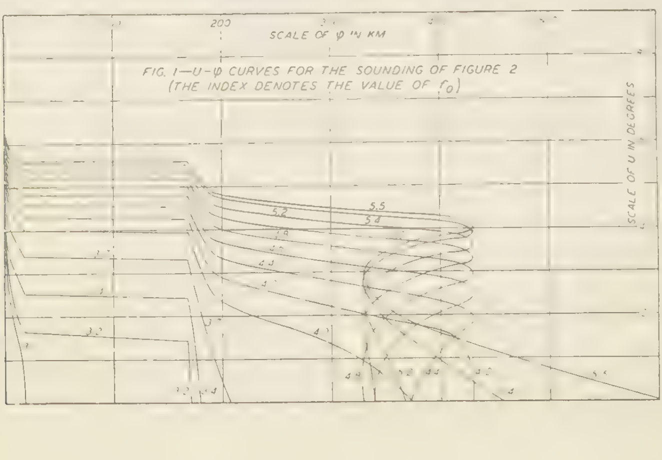
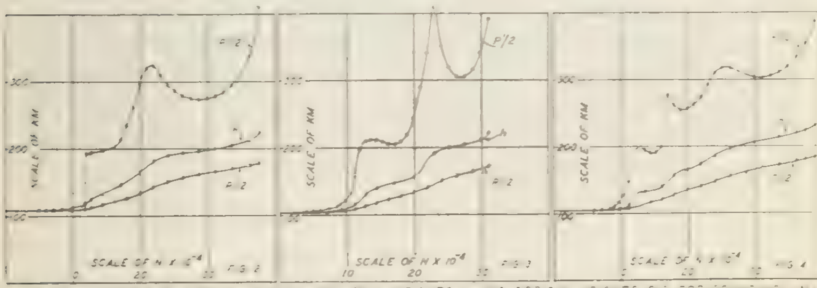


FIG. 1—U-φ CURVES FOR THE SOUNDING OF FIGURE 2 (THE INDEX DENOTES THE VALUE OF f_0)

To find z for a given f_0 the procedure is then to compute u for values of $f<f_0$ and to plot them against the corresponding values of $\phi(f)$ as abscissas. By mechanical integration one then obtains the integral in (12). At $\phi=0$, $u=90°$ and at ϕ (f_0), $u=0$. Examples of such plots are shown in Figure 1, where the index denotes the values of f_0. The equivalent-height data, which were read off Appleton's published curves [4], are plotted in Figure 2. It is seen from Figure 1 that a relatively small contribution to the area under the curve arises from the range of small values of $\phi(f \ll f_0)$. With an extrapolated value of 109 km for h', the areas under the curves in Figure 1 yielded, by (12), the real heights h of Figure 2. For the sake of completeness, the P-curve was computed from (2). Figures 3 and 4 show results of similar interpretations of two other soundings published by Appleton [4].



FIGS. 2, 3, 4—CURVES OF VIRTUAL HEIGHTS h', REAL HEIGHTS h AND OPTICAL HEIGHTS P/2 FOR SOUNDINGS IN ENGLAND (AFTER APPLETON): FIG. 2, 12^h, APRIL 10, 1933; FIG. 3, 10^h, MAY 9, 1933; FIG. 4, 12^h, APRIL 8, 1933 [N $(=1.24 \times 10^4 f_0^2)$ DENOTES THE NUMBER OF ELECTRONS PER CC]

It will be noticed that the lacunae in the P'-data have been interpolated by drawing the smooth dashed curves and that the resulting h-curves are monotone. If the ionization reaches a maximum at a certain height and decreases for some distance thereafter, as in a Chapman region, the P'-curve would become infinite in the interpolated region and the question arises as to the order of magnitude of the error in the h-values introduced by our smoothing process. It was pointed out by de Groot [3] that the distribution of ionization above the level of maximum ionization is strictly indeterminate. A full discussion of a similar difficulty arising in the interpretation of seismic travel-time data will be found in a paper by Slichter [5]. There appears to be no unique way of determining the ionization in regions where it decreases with height, but for the higher regions, where the ionization increases again, the error introduced by substituting a monotone increasing ionization in the anomalous region should decrease with increasing height. The P'-curve for this modified distribution would of course not exhibit any infinities and its approximate representation in the anomalous region is here attempted in the manner indicated in Figures 2, 3, and 4. In order to estimate the magnitude of the (variable) error in the ionization-distribution thus introduced I have computed a theoretical $P'(f)$-curve for a two layered ionosphere having the following structure

$$f_0^2 = 9\left(\frac{y}{5} - \frac{y^2}{100}\right) \text{ for } y < 12.5 \text{ km} \tag{13}$$

$$f_0^2 = 36\left(\frac{y}{50} - \frac{y^2}{10000}\right) \text{ for } y > 12.5 \text{ km} \tag{14}$$

where y denotes in each case the height above the bottom of the E-layer. The ionization reaches a maximum at $y = 10$ and decreases from there on to $y = 12.5$; at 12.5 it begins to increase again and reaches a maximum at $y = 100$, from where it decreases to zero at $y = 200$ km. P' is given by

$$P'(f) = \frac{10f}{3}\ln\left(\frac{3+f}{3-f}\right) \text{ for } f < 3 \tag{15}$$

$$P'(f) = \frac{20f}{3}\ln\left(\frac{\frac{3}{4} + \sqrt{f^2 - \frac{135}{16}}}{f-3}\right) + \frac{100f}{3}\ln\left(\frac{\sqrt{36-f^2}}{\frac{21}{4} - \sqrt{f^2 - \frac{135}{16}}}\right) \text{ for } 3 < f < 6 \tag{16}$$

In the application of the de Groot-Appleton method to this curve equation (15) was used for values of $f < 2.9$, where $\phi = 39.4$, and equation (16) for values of $f > 3.1$, where $\phi = 81.7$. Between these points a smooth monotone curve was drawn giving a value of 68 for ϕ at 3, instead of the infinity. The results of the interpretation of this modified P'-curve are compared with the exact values in Table 1.

Table 1—*Interpretation of modified P′-curve and exact values*

f	y, computed	y, exact
2.9	7.2	7.4
3.1	12.3	14.4
3.2	14.3	15.4
3.6	19.2	20.0
4.0	24.9	25.5
4.4	31.5	32.0
5.0	44.1	44.7
5.5	59.2	60.0
5.8	73.5	74.4

For values of $f < 3$ the method is strictly applicable, so that the error of 0.2 km at 2.9 arises only from inaccuracies in plotting and in the mechanical integration. With the exception of the point 3.1, which is too close to the anomalous region, the agreement is certainly within the error of observations and within the accuracy of (4). Although this single example does not warrant generalizations, it does illustrate the fact that the area of the P'-curve in the vicinity of a logarithmic infinity, such as would arise in a distinct Chapman layer, is not too large to be neglected in the computation of the ionization at levels which are removed from the anomalous regions.

§ 3. *Discussion of results*—The heights of maximum ionization in the F_2-layer are remarkably uniform and rather low, namely 224, 233, and 221 km for cases 2, 3, and 4 respectively. Since the ionization-distribution in the F_2-layer, as determined by the present method, is subject to the least uncertainties it was thought worth while to deduce

the scale-height H for this region. Now for a Chapman layer the ionization N in the vicinity of the level of maximum ionization varies as

$$N = N_0(1 - y^2/4H^2) \tag{17}$$

where y denotes the distance from the level of maximum ionization. Assuming that the last observed frequencies correspond to N_0 in each case, I computed the values of τ defined by

$$\tau = \frac{h_M - h}{\sqrt{1 - N/N_0}} = 2H \tag{18}$$

h_M denoting the (real) height of maximum ionization. These are shown in Table 2, where the vertical distance covered in each case is about 30 km.

TABLE 2—*Values of* $(h_M - h)/\sqrt{1 - N/N_0}$, *where* h_M *and* N_0 *denote the maximum heights and ionization-densities. (The highest observed frequencies are designated by asterisks)*

f	τ_2	τ_3	τ_4
5.6	..	..	*
5.5	*	..	42
5.4	55	..	45
5.2	56	..	53
5.0	57	*	.
4.9	..	46	54
4.8	57	..	..
4.7	..	49	..
4.6	55	..	62
4.5	..	45	..

It is seen that τ is quite uniform for cases 2 and 3, while the relatively large variations in case 4 may be due to the fact that N_0 was not quite reached at the last observed frequency. The values of 20 to 30 km for H in the F_2-layer are less than any of the values deduced hitherto. Thus Appleton [6] quotes a value of about 70 km for H for summer conditions, when the F-layer assumes a dual structure, as in all of the cases treated here; for winter conditions he obtains a value for H of about 40 km. Booker and Seaton [7] find a value of about 55 km for H in Watheroo for $20^h\ 15^m$, March 14, 1939; for the same station, on December 18, 1939, at $16^h\ 15^m$, these authors obtain an ionization-distribution in the F_2-layer which appears to have a scale-height of the order of 90 km. If we adopt a value of about 10 for H in the E-layer, then a considerable fraction of the increase in the F_2 H-values found here could be brought about by the decrease in the molecular weight due to the dissociation of oxygen, which according to Chapman is nearly complete at these levels.

§4. *On the determination of the distribution of electron-collision frequency in the ionosphere*—Measurements of the reflection-coefficient ρ for a given frequency determine the quantity

$$2\int_0^h k\,dz = -\ln \rho \tag{19}$$

By (5)

$$2\int_0^h k\,dz = \frac{1}{c}\int_0^h \nu\left(\frac{1}{\mu}-\mu\right)dz \simeq \frac{\bar{\nu}}{c}\int_0^h dz\left(\frac{1}{\mu}-\mu\right) = \frac{\bar{\nu}}{2c}(P'-P) \qquad (20)$$

where $\bar{\nu}$ denotes a suitable mean value of the electron-collision frequency. Eckersley [8] estimated $\bar{\nu}$ from (20) by observing the temporal variation of P' for a constant frequency and neglecting the variation in P. He found that when the logarithm of the intensity was plotted against P' a straight line was obtained. Similar results were obtained later by Farmer and Ratcliffe [9]. A relationship of this sort is suggested by the run of the curves of P' and P in Figures 2, 3, and 4, which show marked variations in P' accompanied by smaller and monotone changes in P.

We shall show in the following that, subject to the assumptions previously stated, it should be possible to deduce the vertical distribution of ν from nearly simultaneous measurements of ρ for various frequencies. We have by (5)

$$-\ln\rho \equiv F(f) = 2\int_0^h k\,dz = \frac{1}{cf}\int_0^h \frac{\nu f_0^2 dz}{\sqrt{f^2-f_0^2}} = \frac{1}{cf}\int_0^h \left(\nu f_0^2\frac{dz}{df_0}\right)\frac{df_0}{\sqrt{f^2-f_0^2}} \qquad (21)$$

Let

$$G(f_0) = \frac{\nu(f_0)f_0^2}{2c}\left(\frac{dz}{df_0}\right)$$

then equation (21) can be written in the form

$$f^2F(f) = 2f\int_0^f G(f_0)\frac{df_0}{\sqrt{f^2-f_0^2}} \qquad (22)$$

which is of the form (7). Its solution is therefore, by (9)

$$G(f_0) = \frac{\nu(f_0)f_0^2}{2c}\left(\frac{dz}{df_0}\right) = \frac{1}{\pi}\frac{d}{df_0}\int_0^{f_0}\frac{f^2F(f)df}{\sqrt{f_0^2-f^2}} \qquad (23)$$

Or

$$\nu(f_0) = \frac{2c}{\pi f_0^2}\frac{d}{dz}\left[\int_0^{f_0}\frac{f^2F(f)df}{\sqrt{f_0^2-f^2}}\right] \qquad (24)$$

Now, by the de Groot-Appleton method one can determine f_0 (or N) as a function of z, so that the integral in brackets in (24), which is a function of f_0, is thereby determined as a function of z. The numerical differentiation of this latter function with respect to z yields by (24) the value of ν at each height.

We can go a step further and allow partially for the influence of the Earth's magnetic field on ν. A second approximation to k is then [10]

$$k = \frac{\nu}{2c\mu(f+f_L)^2} \qquad (25)$$

where

$$f_L = \frac{eH_L}{2\pi mc} \qquad (26)$$

and H_L denotes the vertical component of the Earth's magnetic field. If in this formula we still use expression (4) for μ, in which the influence of the Earth's magnetic field was not taken into consideration, it can be shown that

$$\nu(f_0) = \frac{2c}{\pi f_0^2} \frac{\mathrm{d}}{\mathrm{d}z} \left[\int_0^{f_0} \frac{(f+f_L)^2 F(f)\mathrm{d}f}{\sqrt{f_0^2 - f^2}} \right] \tag{27}$$

where, as before, $F(f) = -\ln \rho$. It would seem that accurate measurements of the reflection-coefficient as a function of frequency offer an effective method of exploring the upper atmosphere.

References

[1] E. V. Appleton, Phys. Soc., Reports on Progress in Physics, **2**, 129-165 (1936).
[2] It is assumed that the Lorentz polarization-term is zero.
[3] W. de Groot, Phil. Mag., **10**, 521-540 (1930).
[4] E. V. Appleton, Proc. Phys. Soc., **42**, 321-339 (1930).
[5] L. B. Slichter, Physics, **3**, 273-295 (1932).
[6] E. V. Appleton, Q. J. R. Met. Soc., **65**, 324-328 (1939).
[7] H. G. Booker and S. L. Seaton, Phys. Rev., **57**, 87-94 (1940).
[8] T. L. Eckersley, Nature, **135**, 435 (1935).
[9] F. T. Farmer and J. A. Ratcliffe, Proc. R. Soc., A, **151**, 370-383 (1935).
[10] H. G. Booker, Proc. R. Soc., A, **150**, 267-286 (1935).

Department of Geology,
Massachusetts Institute of Technology,
Cambridge, Massachusetts

NOTES

(See also page 235)

8. *Twenty-first annual meeting, American Geophysical Union*—The twenty-first annual meetings of the American Geophysical Union and its eight sections were held in Washington, D. C., April 24, 25, 26, and 27, 1940. During these meetings over 100 scientific papers and reports dealing with researches in geophysics were presented. The newly formed Section of Tectonophysics held its first regular session on April 25, at which five scientific papers were given.

At the General Assembly, April 28, the second award of the Union's Bowie Medal "for distinguished attainment and outstanding contribution to the advancement of cooperative research in fundamental geophysics" was made to Dr. Arthur L. Day, retired director of the Geophysical Laboratory of the Carnegie Institution of Washington. The scientific program of the General Assembly was devoted to a "Symposium on Tectonophysics of the Crust" in the course of which four scientific papers and pertinent discussions were presented.

On the evening of April 25, a "Smoker" was held at the Cosmos Club Auditorium, at which over 125 persons were present. An interesting program consisting of the exhibition of motion-picture film of our National Parks and other entertainment was furnished.

At the session of the Section of Terrestrial Magnetism and Electricity, held on the morning of April 24, the eleven following contributions were included in the program: Geomagnetic tides at Huancayo, by J. Bartels; Physical representations of the geomagnetic field, by A. G. McNish; The general analysis of magnetic fields prescribed on closed surfaces, by E. H. Vestine; Magnetic studies of the Florida Peninsula, by F. W. Lee and J. H. Swartz; Magnetic, seismic, and gravitational traverses across the Atlantic Coastal Plain, by G. P. Woollard; Height of magnetic anomalies, by H. H. Howe; Plans for the magnetic observatory of the Missouri School of Mines at Rolla, by F. C. Farnham; Ionospheric measurements during the solar eclipse of April 7, 1940, by L. V. Berkner and S. L. Seaton; The distribution of electrical elements in the atmosphere near the Earth's surface, by O. H. Gish; Uncharged and total condensation-nuclei at Washington, D. C., by K. L. Sherman; and The nature of solar hydrogen vortices, by R. S. Richardson.

9. *Institute of Terrestrial Magnetism*—In accordance with a decree of the Council of the People's Commissars of the Union of Soviet Socialist Republics, the Sloutzk Magnetic Observatory became on January 1, 1940, an independent organization with the designation of Institute of Terrestrial Magnetism, the present director being N. V. Pushkov.

The principal functions of this newly organized Institute will be (1) the study of geomagnetism and its relations with solar activity, ionosphere, aurora, earth-currents, and allied phenomena and (2) direction of the magnetic service of the U. S. S. R. At present the Institute comprises the following sections: Land Magnetic Survey; Sea Magnetic Survey; Secular Variation; Magnetic Cartography; Theoretical Investigations; Experimental Investigations; Magnetic Information; Net of Magnetic Observatories; and Central Magnetic Observatory in Sloutzk.

In view of the great interest manifested by the Soviet Government in the development of science, there is reason to hope that this new Institute will become an important research-center for terrestrial magnetism.

(See also page 166)

WIDE-RANGE MAGNETOGRAPH AT WASHINGTON, D. C.

An experimental installation has been set up in the Standardizing Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington intended primarily for the experimental development of geomagnetic equipment and appliances. Further, it will serve for the general training of observers assigned to duty at observatories. As in the past, standardization of instruments, tests of sensitive apparatus, and final instruction of observers will be done at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey with the close cooperation of that Bureau and the Department of Terrestrial Magnetism.

This includes a wide-range magnetograph, which will also provide complete records of such violent magnetic storms as those of March 24-25 and 29-30, 1940. La Cour variometers for declination, D, and horizontal intensity, H, and the CIW induction-variometer for vertical intensity, Z, with scale-values adjusted to about 30 gammas per mm, record on the drum of a la Cour magnetograph, with a time-scale of one hour = 15 mm, and automatic time-marks every ten minutes. The photographic sheets are 300 mm wide, and the quiet traces are kept near the center of the sheet so that deflections up to 3500 gammas may be recorded.

As is only too well known, magnetographs working with the ordinary high sensitivities (scale-values of the order of two to eight gammas per mm) often lose the trace during the most intense phase of a storm, not only because the light-spots move beyond the edge of the drum, but also because the rapid movement of the light-spots leaves no trace. This is avoided in the wide-range magnetograph, which has the additional advantages that, because of the small actual movements of the magnets, large variations in D, H, and Z are more faithfully recorded than in the ordinary variometers, in which the magnets may move several degrees from their normal positions perpendicular to the forces they are designed to measure.

It was agreeable to find that D and H are practically free from artificial disturbance although in an area infested with stray industrial and street-railway currents. The influence of street-cars, operating a few miles away, is noticeable, but not serious, in vertical intensity.

Complete record of geomagnetic field-changes appears to require at least three kinds of magnetographs, differing in the scale-values and the time-scales: (1) The ordinary magnetograph with scale-values of two to five gammas per mm and time-scales of 15 to 20 mm per hour; (2) the wide-range recorder for violent storms with scale-values of 25 to 30 gammas per mm and time-scales of 15 to 20 mm per hour; (3) the quick-run recorder for exact timing of sudden commencements and rapid pulsations, with scale-values of one-half to two gammas per mm and time-scales of 240 to 360 mm per hour. Base-line control and temperature-compensation are necessary only for the ordinary magnetograph. So far, only a few observatories (Potsdam-Niemegk and Huancayo) have set up wide-range recorders. It is gratifying to report that the United States Coast and Geodetic Survey is installing wide-range magnetographs at its Cheltenham and Sitka magnetic observatories in line

with that Survey's progressive attitude to advances in geomagnetic research. Since these wide-range recorders require least attention and are immune against artificial disturbance, so that they can be set up even in large towns, it is hoped that, in future, a number of them may be installed so that more information will be obtained during the most interesting moments of geomagnetic history.

J. A. Fleming

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., April 30, 1940

THE MAGNETIC OBSERVATORY AT TOOLANGI

The magnetic observatory at Toolangi is now in full operation again, the recording having started in January 1940. Careful consideration was given to the question of underground construction and its adoption resulted from the decision that it was better to run the risk of dampness than the local risk of loss through forest fire.

The new building is of concrete with three feet of earth over the roof. The building is entirely covered with waterproof coating outside and below which there is adequate provision for efficient drainage, all drainage water being discharged some distance down the hillside. All material used in the building was tested and is non-magnetic.

A wind chute was installed and a current of air was passed through the building for several weeks before the instruments were set up. Jars of calcium chloride are still kept in the rooms and silica gel in the instruments. The results so far seem satisfactory.

The instruments are of the la Cour type and have been lent by the International Polar Year Commission, Dr. la Cour having been good enough to arrange for their loan.

J. M. Baldwin

Melbourne Observatory,
Victoria, Australia, February 7, 1940

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, JANUARY TO MARCH, 1940

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The three columns for each month in Table 1 give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 409-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937); **43**, 83-87, 174-178, 328-331, 491-494 (1938); **44**, 94-99, 215-219, 349-352, 487-491 (1939); **45**, 99-104 (1940).

TABLE 1—*Summary American URSI daily broadcasts of cosmic data, January to March, 1940*

Greenwich date	January			February			March		
	Magnetism			Magnetism			Magnetism		
	Character	Type	GMT beginning disturbance	Character	Type	GMT beginning disturbance	Character	Type	GMT beginning disturbance
			h m			*h m*			*h m*
1	1	*i*	23 50	1	*i*	.. ..	0	...	.. ..
2	1	*i*	.. ..	1	*i*	.. ..	0	...	.. ..
3	1	*i*	14 42	1	*i*	15 00	0	...	.. ..
4	1	*i*	11 00	0	...	.. ..	0	...	.. ..
5	1	*i*	.. ..	0	...	.. ..	0	...	.. ..
6	1	*i*	.. ..	0	...	.. ..	0	...	.. ..
7	1	*i*	.. ..	0	...	.. ..	0	...	.. ..
8	1	*i*	.. ..	1	*i*	23 12	1	*i*	19 30
9	0	...	.. ..	1	*i*	.. ..	1	*i*	.. ..
10	1	*i*	10 20	0	...	.. ..	0	...	.. ..
11	1	*i*	.. ..	0	...	.. ..	0	...	.. ..
12	1	*i*	.. ..	0	...	.. ..	1	*i*	16 00
13	0	...	.. ..	0	...	.. ..	1	*i*	.. ..
14	0	...	.. ..	0	...	.. ..	1	...	.. ..
15	0	...	.. ..	0	...	.. ..	0	...	.. ..
16	0	...	.. ..	0	...	.. ..	0	...	.. ..
17	1	*i*	02 00	0	...	.. ..	0	...	.. ..
18	1	*i*	.. ..	0	...	.. ..	0	...	.. ..
19	0	...	.. ..	0	...	.. ..	1	*i*	14 34
20	0	...	.. ..	1	*i*	01 00	1	*i*	.. ..
21	0	...	.. ..	0	...	.. ..	0	...	.. ..
22	0	...	.. ..	0	...	.. ..	0	...	.. ..
23	0	...	.. ..	1	*i*	22 32	1	*i*	06 18
24	0	...	.. ..	1	*i*	22 09	2	*i*	.. ..
25	1	*o*	01 00	1	...	.. ..	2	*i*	.. ..
26	0	...	.. ..	0	...	.. ..	1	*i*	.. ..
27	0	...	.. ..	0	...	.. ..	1	*i*	.. ..
28	0	...	.. ..	0	...	.. ..	1	*i*	.. ..
29	0	...	.. ..	0	...	.. ..	2	*i*	09 00
30	1	*i*	14 00				2	*i*	.. ..
31	1	*i*	.. ..				2	*i*	.. ..
Mean	0.5	...	.. ..	0.3	...	.. ..	0.7	...	.. ..

Greenwich mean time for ending of storms: 07^h, January 2; 05^h, January 4; 07^h, January 5; 22^h January 12; 17^h, January 25; 21^h, February 2; 18^h, February 3; 06^h, February 9; 08^h, February 20; 01^h February 24; 19^h, February 25; 06^h, March 9; 08^h, March 13; 24^h, March 20; 14^h, March 28; 24^h, April 1

Beginning with October 27, 1938, Mount Wilson discontinued supplying sunspot-numbers, since interested investigators have available the sunspot-counts from Tokyo published regularly in the weekly Science Service Research Aid Announcements and the monthly tabulation of Wolf numbers, promptly prepared at Zürich, which appear monthly in the Monthly Weather Review and quarterly in this JOURNAL.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937,

Table 2—*Kennelly-Heaviside Layer heights, Washington, D. C., January to March, 1940*
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1940	*kc/sec*	*km*	*1940*	*kc/sec*	*km*	*1940*	*kc/sec*	*km*	*1940*	*kc/sec*	*km*
Jan. 3	2,500	120	Jan. 24	2,500	130	Feb. 14	3,600	280	Mar. 6	9,600	370
" "	2,800	130	" "	2,900	140	" "	3,800	230	" "	10,000	350
" "	2,950	310	" "	3,100	*	" "	4,000	250	" "	10,000	440
" "	3,000	260	" "	3,250	240	" "	5,000	260	" "	10,200	370
" "	3,100	230	" "	3,500	220	" "	6,200	290	" "	10,800	550
" "	3,600	240	" "	3,900	240	" "	7,800	300	" "	11,000	*
" "	4,400	250	" "	4,100	260	" "	9,200	310	" 13	2,500	120
" "	2,600	260	" "	4,400	260	" "	9,200	360	" "	2,800	120
" "	5,000	270	" "	6,300	270	" "	9,600	320	" "	3,400	130
" "	5,400	290	" "	7,700	290	" "	9,600	400	" "	3,500	220
" "	6,200	320	" 31	2,500	120	" "	10,000	350	" "	3,550	210
" "	7,000	360	" "	3,000	130	" "	10,000	570	" "	3,600	200
" "	7,400	370	" "	3,100	140	" "	10,600	450	" "	4,000	200
" "	7,400	480	" "	3,150	160	" "	10,800	*	" "	4,600	250
" "	7,800	410	" "	3,200	240	" 21	2,500	120	" "	5,000	270
" "	8,000	450	" "	3,250	200	" "	3,000	130	" "	5,400	280
" "	8,200	520	" "	3,400	210	" "	3,200	220	" "	6,200	280
" "	8,400	*	" "	3,800	230	" "	3,250	270	" "	7,000	290
" 10	2,500	110	" "	4,000	250	" "	3,300	240	" "	7,800	310
" "	2,900	110	" "	4,200	270	" "	3,600	220	" "	8,800	330
" "	3,100	140	" "	4,600	270	" "	4,000	250	" "	8,800	390
" "	3,150	170	" "	5,000	250	" "	4,600	270	" "	9,400	340
" "	3,200	270	" "	6,200	250	" "	6,200	270	" "	9,400	570
" "	3,250	230	" "	7,000	260	" "	7,000	270	" "	9,800	390
" "	3,300	220	" "	7,800	270	" "	7,800	290	" "	10,200	520
" "	3,600	230	" "	8,200	280	" "	8,600	310	" "	10,400	*
" "	4,000	240	" "	8,600	300	" "	8,600	360	" 20	2,500	120
" "	5,400	250	" "	8,600	340	" "	9,800	350	" "	3,450	120
" "	6,200	260	" "	8,800	300	" "	9,800	480	" "	3,500	220
" "	7,000	270	" "	8,800	400	" "	10,000	360	" "	3,800	200
" "	7,800	280	" "	9,200	340	" "	10,400	420	" "	4,000	230
" "	8,600	290	" "	9,600	470	" "	10,600	*	" "	4,400	290
" "	9,800	320	" "	9,800	*	" 28	2,500	130	" "	4,600	380
" "	9,800	380	Feb. 7	2,500	130	" "	3,200	140	" "	4,800	510
" "	10,200	330	" "	2,800	130	" "	3,300	170	" "	5,000	430
" "	10,200	400	" "	3,000	130	" "	3,350	240	" "	5,400	370
" "	10,600	350	" "	3,100	140	" "	3,450	210	" "	5,800	390
" "	10,600	560	" "	3,200	240	" "	3,700	190	" "	6,200	410
" "	11,000	390	" "	3,300	180	" "	4,100	240	" "	6,200	480
" "	11,400	470	" "	3,400	160	" "	4,600	280	" "	6,400	410
" "	11,600	*	" "	3,500	280	" "	6,600	290	" "	6,400	550
" 17	2,500	120	" "	3,600	230	" "	9,000	320	" "	6,800	410
" "	2,900	130	" "	3,700	220	" "	9,000	400	" "	7,000	450
" "	3,100	140	" "	4,200	250	" "	9,400	340	" "	7,200	580
" "	3,150	150	" "	4,600	260	" "	9,400	450	" "	7,400	*
" "	3,200	230	" "	5,400	270	" "	9,800	370	" 27	3,000	110
" "	3,250	220	" "	7,000	280	" "	10,200	440	" "	3,400	130
" "	3,400	210	" "	8,600	300	" "	10,400	*	" "	3,600	210
" "	3,800	210	" "	9,200	300	Mar. 6	2,500	120	" "	3,800	200
" "	4,000	250	" "	9,200	350	" "	3,200	120	" "	4,000	210
" "	4,200	260	" "	9,600	310	" "	3,400	140	" "	4,200	230
" "	4,600	250	" "	9,600	380	" "	3,500	160	" "	4,400	250
" "	5,400	250	" "	10,000	330	" "	3,550	200	" "	4,600	290
" "	6,200	250	" "	10,000	430	" "	3,600	220	" "	4,800	420
" "	7,000	260	" "	10,400	350	" "	3,650	200	" "	5,000	480
" "	7,800	270	" "	10,800	530	" "	3,800	220	" "	5,200	350
" "	9,400	280	" "	11,000	*	" "	4,000	240	" "	5,600	330
" "	10,200	300	" 14	2,500	130	" "	4,600	260	" "	6,000	370
" "	10,200	360	" "	3,200	150	" "	4,800	270	" "	6,400	370
" "	10,400	310	" "	3 250	240	" "	6,200	280	" "	6,400	520
" "	10,400	400	" "	3 300	220	" "	7,800	280	" "	7,000	420
" "	10,800	340	" "	3,350	230	" "	8,600	290	" "	7,200	530
" "	11,200	430	" "	3,500	190	" "	9,600	320	" "	7,400	*
" "	11,400	*									

* = No value obtained.

TABLE 3—*American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for January to March, 1940*

Day	January			February			March		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	0.0	0.0	0.0	0.9	1.1	1.0	0.1	0.0	0.1
2	0.4	0.2	0.3	0.5	0.4	0.4	0.0	0.2	0.1
3	0.6	1.5	1.0	0.1	0.6	0.4	0.0	0.2	0.1
4	0.6	1.0	0.8	0.0	0.1	0.1	0.0	0.1	0.0
5	0.7	0.3	0.5	0.0	0.3	0.1	0.0	0.0	0.0
6	0.5	0.8	0.6	0.3	0.6	0.5	0.0	0.3	0.1
7	0.4	0.9	0.6	0.5	0.4	0.4	0.2	0.2	0.2
8	0.4	0.2	0.3	0.3	0.4	0.3	0.2	0.6	0.4
9	0.0	0.6	0.3	0.4	0.1	0.2	0.9	0.2	0.6
10	0.3	1.3	0.8	0.0	0.2	0.1	0.1	0.0	0.0
11	0.7	1.1	0.9	0.0	0.5	0.2	0.0	0.0	0.0
12	0.9	0.7	0.8	0.5	0.7	0.6	0.0	0.6	0.3
13	0.2	0.0	0.1	0.0	0.4	0.2	0.4	0.1	0.2
14	0.0	0.0	0.0	0.2	0.0	0.1	0.4	0.1	0.2
15	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
16	0.5	0.6	0.5	0.0	0.3	0.1	0.1	0.2	0.1
17	0.4	0.6	0.5	0.0	0.1	0.0	0.0	0.0	0.0
18	0.4	1.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0
19	0.6	0.3	0.4	0.0	0.1	0.0	0.5	0.9	0.7
20	0.1	0.4	0.3	0.9	0.6	0.7	0.9	0.8	0.9
21	0.0	0.1	0.0	0.6	0.4	0.5	0.4	0.3	0.4
22	0.1	0.5	0.3	0.4	0.2	0.3	0.1	0.2	0.1
23	0.3	0.4	0.3	0.0	0.3	0.1	0.9	1.1	1.0
24	0.4	0.5	0.5	0.4	0.4	0.4	1.1	2.0	1.5
25	0.5	0.4	0.4	1.0	1.1	1.0	2.0	1.7	1.9
26	0.0	0.1	0.0	0.4	0.3	0.3	1.3	0.9	1.1
27	0.1	0.2	0.2	0.0	0.0	0.0	1.1	0.8	1.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.5	0.6
29	0.0	0.5	0.2	0.4	0.4	0.4	0.5	2.0	1.2
30	0.6	0.9	0.8				2.0	1.6	1.8
31	0.8	1.1	0.9				1.7	1.8	1.8
Means.	0.3	0.5	0.4	0.3	0.3	0.3	0.5	0.6	0.5

the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March, 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for Table 2 of Kennelly-Heaviside Layer heights which are self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department

of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_4, and its values for the first twelve, second twelve, and twenty-four hours of each Greenwich day for January to March, 1940, are given in Table 3.

H. F. Johnston

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., April 24, 1940

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, JANUARY TO MARCH, 1940

Greenwich mean time						Range hor. int.
Beginning			Ending			
1940	*h*	*m*	*d*	*h*	*m*	γ
Jan. 3	14	39*	3	24	..	170
10	10	19*	12	22	..	100
18	8	..	19	3	..	150
30	9	..	2	10	..	115
Feb. 24	22	09*	25	20	..	95
Mar. 23	6	17*	28	11	..	>850
29	16	03*	1[a]	17	..	420

*Sudden commencement. [a]April 1.

The magnetic disturbances beginning on January 3, 10, 30, and February 24 were probably all associated with the very large group of sunspots whose successive central meridian passages occurred on January 5.5 (Mount Wilson No. 6725), February 1.8 (No. 6741), and February 28.5 (No. 6756).

The same group crossed the central meridian for the fourth time on March 27.0 (No. 6784). On the previous appearances it had been a typical bipolar group, but now all that remained was the principal preceding member—a round stable unipolar spot.

A series of magnetic disturbances which began on March 23 was probably associated with a new group (No. 6783) which had developed about 10° west and 3° north of No. 6784. The new group, although easily visible without a telescope, was never so large as the other group had been in January. Within a large irregularly shaped penumbra were several umbrae, some with positive, the others with negative magnetic fields. Large active groups of this kind, in which magnetic poles of opposite sign occur within the same penumbra, are much more frequently associated with great magnetic storms than are regular bipolar groups like the one of January.

The magnetic fluctuations beginning on March 23 were rapid but of small amplitude until March 24 when a great storm began suddenly at $13^h 49^m$. The most disturbed period was from about $15^h 43^m$ to $18^h 57^m$. Although the variations were so rapid that portions of the curve were not

Day	January 1940						February 1940						March 1940					
	K_2						K_2						K_2					
	Whole disk	Central zone	*Ha* bright	*Ha* dark	No. groups	Mag'c char.	Whole disk	Central zone	*Ha* bright	*Ha* dark	No. groups	Mag'c char.	Whole disk	Central zone	*Ha* bright	*Ha* dark	No. groups	Mag'c char.
1	..	..	..	..	3	0	..	..	..	..	..[h]	1	3	3	3	3	7	0
2	..	..	..	..	4	0.5	..	..	..	..	..	0.5	3	3	3	3	6[e]	0
3	..	..	..	..	4	1	..	..	..	..	..	0	3	3	3	3	7[a]	0
4	..	..	..	..	..	0.5	3	3	3	2	3	0	3	2	3	3	8	0
5	3	3	3	3	4[a]	0.5	3	3	2	2	4[e]	0	3	2	3	3	7	0
6	..	..	..	..	3	0.5	3	3	2	2	4	0.5	3	1	3	3	6	0
7	..	..	..	..	..	0.5	3	3	2	2	5[b]	0.5	3	2	3	3	7[b]	0
8	..	..	..	..	..	...	3	2	3	2	6	0	2	2	2	3	7	0
9	..	..	..	..	..	0.5	3	2	2	2	6[b]	0	2	3	2	3	4	0.5
10	..	..	..	..	..	0.5	3	2	3	3	6	0	..	..	..	..	..	0
11	..	..	..	..	..	1	3	3	2	2	5[e]	0	3	3	3	3	6	0
12	3	2	2	3	3	0.5	2	3	..	..	5	0.5	3	3	3	2	5	0
13	3	2	2	3	5	0	3	2	2	1	7[b]	0	3	2	3	2	8	0
14	3	2	2	3	5	0	..	..	..	..	..	0	3	1	3[d]	2	8	0.5
15	3	3	3	3	5[b]	0	3	2	2	1	6	0	3	2	3	1	6	0
16	3	3	3	2	6[e]	0	3	3	3[c]	2	5	0	3	2	3	1	6	0
17	3	3	3	3	6	0.5	3	3	3[d]	1	4[f]	0	2	2	..	..	7	0
18	3	2	2	2	5	1	3	3	3	2	4	0	..	..	..	..	5	0
19	3	3	2	2	5	0.5	3	2	3	2	6	0	..	..	..	..	..	0.5
20	3	4	3	2	7	0	2	2	2[d]	1	6	0.5	3	2	3	2	7	0.5
21	3	3	3	2	6	0	..	..	..	..	..	0.5	3	0	3[d]	1	8	0
22	..	..	..	..	..	0	..	..	..	..	..	0	3	1	3	1	9	0
23	..	..	..	..	..	0	2	1	2	1	5	0	3	3	3	1	10	1
24	2	2	..	..	3	0	2	2	2	2	4	0.5	3	4	3[c]	1	12	2
25	2	1	2	2	4	0	..	..	..	..	..	1	3	3	3	2	12	2
26	..	..	..	..	4	0	..	..	..	..	..	0	..	..	..	..	12[h]	1
27	..	..	..	..	3	0	3	3	3	2	6	0	..	..	..	..	10	1
28	2	0	2	2	2	0	3	2	3	3	6[h]	0	..	..	..	..	10	0.5
29	..	..	..	..	4	0	3	3	3	3	6[a]	0	4	3	4	3	..	2
30	..	..	..	..	..	0.5							4	4	3	3	8	2
31	..	..	..	..	..	1							..	..	..	..	..	2
Mean	2.8	2.4	2.5	2.5	4.3	0.3	2.8	2.5	2.5	1.9	5.2	0.2	3.0	2.3	3.0	2.3	7.7	0.5

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

[a, b] Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

[c, d] Very bright chromospheric eruptions; (*c*) less than 30° from the center of the disk, (*d*) more than 30° from the center of the disk.

[e, f, g, h, i, j, k, l] Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

recorded, the values of H ranged at least from 220γ above normal to 630γ below. An aurora of moderate intensity was observed at Mount Wilson on the night of March 24 from dark until the Moon rose (March 25, $03^h 30^m$ GMT). The aurora was not visible in the light of the nearly full Moon. During March 25 the horizontal intensity was from 200γ to 130γ below normal; on March 26, 150γ to 50γ below.

A second storm which began on March 29 at $16^h 03^m$ and continued until April 1, although not so great as the first one, also was very intense. The Earth's field was calm from April 1, 17^h to April 2, 18^h when a lesser storm of about 24 hours' duration began. Thus the Earth's field was disturbed from March 23, $06^h 17^m$, to April 3, 22^h.

At the beginning of the magnetic disturbance on March 23 the large sunspot (No. 6783) was 35° east of the central meridian; during the most intense part of the storm on March 24 it was 20° east of the central meridian, which it crossed on March 26.3, 19° from the center of the disk It reached the west limb on April 1 and hence was not in view during the disturbance on April 2 and 3. These storms occurred near the "equinoctial maximum" of magnetic activity. It is of interest to note that at this time the inclination of the Sun's equator was such that this group was as far from the center of the solar disk at central-meridian passage as a spot in that latitude (+13°) can be.

The magnetic activity on January 18 may have been associated with group No. 6730, which crossed the central meridian on January 16, 4° south of the center of the disk.

SETH B. NICHOLSON
ELIZABETH STERNBERG MULDERS

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY,
Pasadena, California

THE EIGHTH AMERICAN SCIENTIFIC CONGRESS

The Eighth American Scientific Congress was held in Washington, D. C., May 10-18, 1940, under the auspices of the Government of the United States of America. Congresses previously held with their places of meeting are as follows: Buenos Aires, 1898 (on the occasion of the celebration of the Silver Jubilee of the Argentine Scientific Society); Montevideo, 1901; Rio de Janeiro, 1905; Santiago de Chile, 1908; Washington, D. C., 1915-16; Lima, 1924-25; Mexico City, 1935. At the Lima Congress a decision was reached that the next meeting of the series should take cognizance of the fact that it would be the seventh of the international assemblies inaugurated at Buenos Aires in 1898, three of which had been termed "Latin-American" and three "Pan-American" Scientific Congresses. This Seventh Congress was to have taken place at San José, Costa Rica, in 1929, but because of the crisis which paralyzed the economic world in that year, the convening of the Seventh Congress was twice postponed, it finally being held in Mexico City in 1935.

The two cardinal purposes of the Eighth American Scientific Congress were: (1) To advance scientific thought and achievement; (2) to assist in celebrating the fiftieth anniversary of the founding of the Pan American Union. In the preparation of the program, a special effort was made to obtain an adequate presentation of current scientific activities in countries of the Americas other than the United States.

In the general program which was presented in eleven sections, considerable prominence was given to humanistic, economic, and social sciences. However, Section III was devoted to the geological sciences and Section VI to the physical and chemical sciences. In Section III papers were presented dealing with general geology, economic geology (petroleum and metalliferous deposits), tectonics, and volcanology. In Section VI, three of the sessions were devoted to (1) astronomy, physics of the Earth, and general physics, (2) meteorology, and (3) promotion of physics, radio transmission, and cosmic rays.

In these sessions, papers of interest to the readers of this JOURNAL were given as follows. The National Geographic Society's expedition to Brazil for the solar eclipse of October 1, 1940, by I. C. Gardner; Geomagnetic research in the Americas, by J. A. Fleming; National organizations for the advancement of physics in the United States of America, by H. A. Barton; Possibility for investigation of the physical sciences in Cuba, by M. Gran, Radio-transmission conditions in equatorial regions from observations in the Americas, by L. V. Berkner; A radio transmission anomaly—Cooperative observations between the United States of America and Argentina, by J. H. Dellinger and A. T. Cosentino, Observations of radio fade-outs and terrestrial magnetism, by P. J. Noizeux; The Earth's magnetic field and its influence on cosmic rays, by M. S. Vallarta; Statistical analysis of cosmic rays, by A. Baños, Jr.

The program of Section III (Geological Sciences) included the following papers of geophysical interest: Structure and physiography of the Western Andes, by J. L. Rich; Structure and gravity field of the Carribbean region, by H. H. Hess; Seismicity of Central and South America, by B. Gutenberg and C. F. Richter; Geophysical methods in the Americas, by E. DeGolyer; Geology of the oil deposits of Venezuela, by P. I. Aguerrevere; The application of physical methods to the study of volcanism, by L. H. Adams; The general geological and tectonic features of volcanoes, by P. C. Sánchez; Notes on the volcanism of the West Indies, by F. A. Perret; The active volcanoes of Central America, by E. G. Zies.

The proceedings of the Congress containing all these papers will be published by the United States Government.

At the final plenary session on May 17, the Honorable Sumner Wells, President of the Congress, in his address of adjournment, stated that not only had the cause of science been advanced but that the entire fabric of inter-American relations had been strengthened. Out of the ruins of this darkened and strife-torn world, he envisioned the rising of a brighter and better civilization where freedom and the right to seek the truth would be assured to all mankind.

At this session also, four resolutions emanating from Section VI (Physical and Chemical Sciences) were adopted of which two resolutions concern geomagnetism; these are as follows:

Resolution (2) regarding cosmic-ray research

WHEREAS: The question of the origin and nature of the cosmic rays which reach the atmosphere of the Earth from outer space is a problem of world-wide interest;

In addition to their own scientific importance, the effects of cosmic rays are intimately related to other problems of great scientific and practical interest, such as the variations of the Earth's magnetic field and the propagation of radio waves through the atmosphere of the Earth; and

The full understanding of cosmic rays and their effects requires the accumulation of data from observations in all latitudes,

The Eighth American Scientific Congress

RESOLVES: To bring these facts to the attention of institutions of learning and of research in all the American countries, and suggest that consideration be given to the possibility of establishing permanent stations for observations on cosmic rays to supplement those stations now in operation.

Resolution 3, regarding geomagnetic surveys and observatories

WHEREAS: The need in the Americas for more complete and accurate magnetic data is constantly increasing because of the extension of navigation by air and sea as well as for the theoretical and practical developments of geophysics;

The Western Hemisphere embracing the continents of South and North America and their adjoining Pacific, Atlantic, and Southern oceans invites such studies because of the unique geographic and geophysical characteristics and, in particular, the rapid secular magnetic changes in certain regions;

Additional magnetic surveys and extensions of existing surveys are urgently needed in the Western Hemisphere for investigations of secular variation and magnetic anomalies; and

Additional magnetic observatories, particularly in South America and on islands, are needed to make for a better distribution of the existing observatory-net of 15 stations in the Western Hemisphere so essential to a study of the unique features of magnetic disturbances, their solar and lunar correlations, and definition of magnetic activity for practical application to wired and wireless communication,

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RESOLVES: That the American Republics be urged to continue as well as to inaugurate magnetic-survey work in their territories, individually or cooperatively.

That existing magnetic observatories be supported in the extension of their programs and that there be established in strategic positions such as Easter Island, Belem, Brazil, and Magallanes, Chile, magnetic observatories to effect a better distribution of the net in the Western Hemisphere.

The Congress was opened on May 10 by a formal inaugural session at which an address of welcome was given by the President of the United States. In the course of the Congress social functions including official luncheons and banquet, garden parties, receptions, and a special concert by the National Broadcasting Company's Symphony Orchestra, were provided. Visits to scientific institutes and Government bureaus as well as to places of interest in and near Washington were arranged. Excursions to the famous caverns of Luray and the colonial city of Williamsburg were also made. After the Congress the delegates visited Philadelphia and New York and were accorded a special "Congress Day" at the New York World's Fair.

It was decided that the Ninth American Scientific Congress will be held in Havana, Cuba.

H. D. Harradon.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

MIDDAY F_2-REGION CRITICAL FREQUENCIES FOR DEAL, NEW JERSEY

Midday F_2-region critical frequencies as obtained at Deal, New Jersey, are given in Table 1. The values given are in mc/sec and are for the *o*-component. The period covered by these readings is from May 1939 to April 1940.[1] Nearly all of the readings were obtained near noon. Most of the exceptionally low values were obtained during disturbed conditions. The readings were obtained by G. M. Eberhardt and the writer.

[1]See Terr. Mag., 44, 212 (1939) for values from June 1938 to April 1939.

TABLE 1—*Midday F_2-Region Critical Frequencies for Deal, New Jersey*
(*Values are for the o-component in mc/sec*)

Date	1939								1940			
	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1	8.2	8.7	......	......	8.9	9.1	12.3	11.2	......	9.3	9.6	6.6
2	6.4	5.3	......	7.5	8.9	11.8	11.6	11.6	10.4	9.5	10.5	5.6
3	5.8	5.6	......	7.5	7.8	9.5	12.0	11.3	8.1	......	10.0	6.5
4	9.2	6.0	......	6.7	8.4	12.3	12.8	10.8	9.7	9.5	11.0	7.9
5	9.2	6.3	5.0	6.5	9.1	11.0	11.7	10.4	9.2	9.0	10.0	8.4
6	5.7	8.7	5.4	7.9	7.3	11.5	11.7	9.8	9.8	9.1	10.0	8.4
7	5.2	8.5	7.2	7.8	8.6	......	......	9.7	10.1	9.9	9.9	9.0
8	6.4	8.6	......	7.4	9.6	......	12.1	9.9	10.0	9.5	10.3	10.3
9	7.5	7.7	......	8.4	......	7.8	11.4	......	9.6	9.7	7.8	10.2
10	9.4	......	7.2	7.6	......	10.2	11.6	10.7	10.4	9.7	8.8	9.8
11	8.7	......	8.0	8.7	10.1	11.0	11.4	10.1	9.7	9.8	9.0	9.4
12	8.0	......	7.2	7.0	8.5	12.0	......	11.0	10.1	10.7	10.5	9.5
13	5.9	......	7.9	6.4	9.8	12.3	9.1	10.8	9.2	9.5	9.3	......
14	9.7	......	5.5	6.1	8.5	......	12.1	10.9	9.2	9.3	9.9	7.7
15	7.4	......	5.5	7.7	8.5	......	12.4	11.4	9.0	8.8	9.7	8.2
16	7.4	......	6.2	5.9	8.7	11.3	11.8	10.9	10.7	9.8	9.4	7.1
17	9.7	......	6.1	6.1	11.3	11.1	......	11.1	10.7	......	10.0	7.2
18	7.8	......	6.7	8.1	10.7	13.1	11.2	11.1	11.4	9.1	9.2	6.3
19	6.6	......	6.6	......	7.5	11.7	11.6	10.4	8.4	9.7	8.0	8.4
20	5.6	......	......	......	6.1	12.1	11.8	9.4	8.5	9.6	5.9	8.6
21	7.0	......	5.8	9.3	8.7	......	12.1	11.1	8.8	9.6	8.6	7.1
22	7.7	......	6.0	......	9.9	......	10.4	11.2	8.7	9.9	8.3	5.8
23	7.0	6.2	7.1	4.6	......	12.4	......	......	10.0	9.9	......	7.8
24	5.8	......	7.4	4.9	......	13.3	12.1	......	......	6.3	......	8.6
25	7.3	......	6.9	6.9	11.1	12.8	......	......	8.9	4.9	6.2	7.8
26	5.8	6.4	5.1	8.0	......	12.6	......	10.3	8.4	9.0	8.3	4.8
27	6.7	6.1	......	9.3	10.5	13.3	10.7	10.5	8.4	9.1	7.3	5.9
28	6.0	7.2	5.9	10.1	......	......	11.4	9.7	8.6	9.2	5.8	6.3
29	7.7	5.5	6.2	8.1	12.0	......	10.6	9.7	10.2	9.8	......	7.7
30	6.5	7.7	7.1	6.9	12.6	13.8	11.1	......	9.0		......	8.0
31	7.0		7.8	8.6		13.0		......	8.8		......	
Means	7.2	7.0	6.5	7.4	9.3	11.7	11.5	10.6	9.4	9.2	9.0	7.8

No distinct critical frequency observed on March 29, 30, 31, 1940.

W. M. GOODALL

BELL TELEPHONE LABORATORIES,
Deal, New Jersey, April 30, 1940

NOTE ON SCALE-VALUE EQUATION OF THE CIW INDUCTION-VARIOMETER

H. H. Howe of the United States Coast and Geodetic Survey has recently called attention to the fact that the equation of equilibrium for the CIW induction-variometer [Terr. Mag., **41**, 161-172 (1936)] should contain the term Z^2 instead of Z. Including this modification in the equation introduces a factor of $1/2$ in the theoretical scale-value equation of the instrument, higher order terms being neglected. Fortunately this blunder occasioned no error in practice since the scale-value has been determined empirically thus far.

No important modifications of the theoretical operating-characteristics of the instrument result from the inclusion of this correction pro-

vided the field-changes are small as compared with the total value of vertical intensity. However, as Mr. Howe points out, serious effects may be encountered in regions where vertical intensity is extremely small, namely, close to the magnetic equator. In particular, the variometer would be unable to discriminate between positive and negative values of vertical intensity if the variations in that element pass through zero. This condition can be remedied by using an auxiliary magnet and thus increasing the value of vertical intensity so that at no time will the modified field reverse sign. If an auxiliary magnet is used no restrictions are imposed on the utility of the variometer by recognition of the correction in the equation of equilibrium.

A. G. McNish

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., May 20, 1940

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS AT WASHINGTON, D. C., JANUARY TO MARCH, 1940[1]

The following ionosphere data are in continuation of those published in this Journal[2] and in each issue subsequently.

Table 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.* (Average for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$
h	*m*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/s[illegible]*
			January, 1940[a]						*February, 1940*			
00			318			3250			313			371[illegible]
01			327			3240			307			373[illegible]
02			320			3210			306			360[illegible]
03			304			3320			304			349[illegible]
04			289			3370			301			338[illegible]
05			286			3200			299			318[illegible]
06	115≠		298	830≠		2960	120≠		308	820≠		290[illegible]
07	116≠		285	1200≠		3550	116≠		256	1660≠		461[illegible]
08	115≠		230	2040		5980	125≠	229	234	2300		674[illegible]
09	124≠		231	2600		7610	120≠	220	246	2740		751[illegible]
10	127	230	257	2900		8620	122	214	254	3030		827[illegible]
11	122	228	258	3100		9320	120	206	259	3210	4100*	885[illegible]
12	121	227	257	3190		9350	120	210	264	3270	4200*	935[illegible]
13	121	225	262	3150		9360	121	218	260	3280	4200*	937[illegible]
14	121	232	260	2990		9400	121	220	256	3190	4150*	930[illegible]
15	125	234	252	2740		9350	123	223	256	2970		938[illegible]
16	119≠		237	2360		8910	122≠	229	241	2660		929[illegible]
17	120≠		230	1760≠		8100	116≠	228	231	2060		872[illegible]
18	112≠		236	1070≠		7140	111≠		226	1300		780[illegible]
19			241			6000			236			662[illegible]
20			256			4640			248			558[illegible]
21			285			3980			265			465[illegible]
22			297			3570			283			415[illegible]
23			306			3350			298			384[illegible]

[a] $f^\circ_{F_1}$ not well defined during January.

[1] Communicated by the Director of the National Bureau of Standards of the United States Department of Commerce.
[2] T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*—Continued

(Averages for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$
h	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*
			March, 1940			
00			314			4800
01			319			4520
02			319			4300
03			307			4170
04			302			3920
05			302			3640
06	120*		287	1330*		3910
07	122*		247	2170		5920
08	122	230	301	2720	3930*	7000
09	117	220	307	3090	4260*	7490
10	112	210	308	3340	4480	7860
11	113	206	318	3490	4550	8160.
12	112	205	334	3570	4580*	8610
13	112	212	332	3570	4500*	8770
14	113	219	316	3470	4420	9020
15	116	230	305	3280	4370*	9250
16	123	232	372	2960	4200*	9180
17	117*	243	301	2509	3800*	9050
18	122*		241	1830		8710
19	120*		256	1225*		7620
20			265			6630
21			275			6050
22			293			5490
23			300			5100

The data given here are in part somewhat different from those presented graphically each month in *Proceedings of the Institute of Radio Engineers*, because those are for undisturbed days while these are for all days of the month.

These data also give implicitly the maximum ionization-densities of the ionosphere layers. The equivalent electron-density in electrons per cubic centimeter is 0.0124 times the square of the critical frequency.

Key to symbols:

EST = Eastern Standard Time (75° west meridian time).

♯ = manual measurements made on Wednesdays; other data were usually obtained daily.

* = less than ten measurements.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE.
Washington, D. C.

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

January to March, 1940

(*Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^{h} 01^{m}.3 W. of Gr.*)

January 3-4—A small storm began abruptly at 14^{h} 41^{m} GMT, January 3, with a sharp decrease in the horizontal intensity. The field was very disturbed from 15^{h} to 17^{h}. Thereafter the trace began a gradual return to normal values. The disturbance ended about 24^{h}, January 4. At times during the stormiest period the spots moved so rapidly, it was not possible to separate the three components. Ranges: *D*, 170′; *H*, 1172 gammas; *Z*, 1135 gammas.

January 10-12—A small disturbance started gradually about 12^{h} GMT, January 10. The greatest activity occurred from 13^{h} to 16^{h}; thereafter the field gradually returned to normal. The trace remained moderately disturbed for several days with large bays and short intervals of moderate disturbance. Ranges: *D*, 80′; *H*, 744 gammas; *Z*, 728 gammas.

January 18-19—A small disturbance began gradually at about 08^{h} GMT, January 18, with slowly decreasing values of the field. The major portion of the disturbance took place between 15^{h} and 21^{h}. The disturbance ended about 03^{h}, January 19. Ranges: *D*, 123′; *H*, 1078 gammas; *Z*, 557 gammas.

January 30-February 3—An extended period of disturbed conditions began gradually during the first part of January 30 and ended at the close of February 3. It consisted chiefly of large bays with occasional sharp motions.

February 20-22—An extended period of mildly disturbed conditions began about 00^{h} GMT, February 20, and continued until about 12^{h}, February 22.

February 24-25—A sudden commencement at 22^{h} 08^{m} GMT, February 24, preceded a badly disturbed period. The disturbance gradually increased with slow, large-amplitude motion with decreasing field-strengths. After 14^{h}, February 25, a slow recovery to normal conditions set in. The conditions reached normal by 24^{h}, February 25. Ranges: *D*, 66′; *H*, 689 gammas; *Z*, 750 gammas.

March 23-25—A very severe storm began with a sudden commencement at 09^{h} 06^{m} GMT, March 23. The storm gradually increased in intensity until at 13^{h} 48^{m}, March 24, with a sudden decrease of 300 gammas in the horizontal intensity, the main portion of the storm began. Until about 12^{h}, March 25, the motion of the traces was so great and of such violence that it was impossible to follow the record for several hours. The storm ended about 07^{h}, March 26. Conditions remained disturbed until the following storm. Due to the exceptionally large, rapid motion of all components the accurate determination of the ranges is not possible. It is believed that the *D*-maximum, *H*-maximum, and *H*-minimum were lost by the spots going off the paper. The identification of the other points is uncertain. Estimated ranges: *D*, 279′; *H*, 2260 gammas; *Z*, 1200 gammas.

March 29-April 1—Closely following the previous storm a second severe one began gradually at about 09^{h} 30^{m} GMT, March 29, and then

increased to maximum storminess at 16^h. A slight lull occurred from 17^h, March 30, to 10^h, March 31. After 19^h, March 31, there was a gradual return to normal. The trace remained very badly disturbed until 18^h, April 1. As in the case of the preceding storm the motion at times was so rapid that it was impossible to separate the various components. It is believed that the D-maximum, H-maximum, and H-minimum were lost by the regular and reserve spots going off the paper. Estimated ranges: D, 281′; H, 1800 gammas; Z, 1400 gammas.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory

January to March, 1940

(*Latitude 38° 44′.0 N., longitude 76° 50′.5 or 5^h $07^m.4$ W. of Gr.*)

January 3-4—A mild storm, which was very active during the first two hours, began at 14^h 41^m GMT, January 3, when H decreased 158 gammas in 23 minutes. The storm ended at 05^h, January 4. Ranges: D, 26′; H, 265 gammas; Z, 54 gammas.

January 4-5—After several hours of quiet a disturbance of modest activity began at 10^h 47^m GMT, January 4. The disturbance continued until 07^h, January 5. Ranges: D, 17′; H, 142 gammas; Z, 31 gammas.

February 24-26—A moderate disturbance began with a sudden commencement at 22^h 10^m GMT, February 24. It ended at 09^h, February 26. Ranges: D, 26′; H, 107 gammas; Z, 88 gammas.

March 8-9—A moderate disturbance lasting 11 hours began at 19^h 30^m GMT, March 8. Ranges: D, 28′; H, 110 gammas; Z, 68 gammas.

March 23-28—At 06^h 17^m GMT, March 23, H increased rapidly about 43 gammas in five minutes, ushering in a disturbance which on March 24 developed into a great magnetic storm. The elements were active but with small amplitudes until 13^h 49^m, March 24, when the great storm began. However, from 20^h, March 23, to 05^h, March 24, there was a gradual rise and fall of the Z-curve of about 160 gammas each way and a corresponding fall and rise in the H-curve. All the elements were very greatly disturbed beginning at 13^h 49^m, March 24, and ending at 13^h, March 25. During this interval the ranges were: D, 2° 17′; H, 850 gammas; Z, 1100 gammas. The storm then continued in mild form until 15^h 05^m, March 25, when there was another outburst of activity until 02^h, March 26, although this phase of the storm was not nearly so great as the earlier phase. The ranges during this interval were: D, 1° 15′; H, 200 gammas; Z, 300 gammas. The disturbance then gradually subsided, ending at 14^h, March 28.

March 29-April 2—At 09^h GMT, March 29, it began to storm again, mildly at first, but suddenly, at 16^h 03^m, all three elements became very active and continued so for the next 24 hours. The ranges during this phase of the storm were: D, 1° 45′; H, 500 gammas; Z, 800 gammas. The storm continued with less fury until 09^h 39^m, March 31, and during the next two hours both H and Z reached extremely low values, the H-reserve spot going off the magnetogram. West declination during this time was high. After 13^h, March 31, the storm continued more moderately and ended at 05^h, April 2.

Albert K. Ludy, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1940

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or 7h 23m.3 W. of Gr.)

January 3—A moderately severe but short-lived storm began at 14h 40m GMT, January 3, and ended about three hours later. The principal feature was a drop in *H* of 198 gammas followed by a return to its normal value in an hour and a half. *D* fluctuated through a range of 12′ and *Z* was slightly disturbed.

January 30-February 2—A period of moderate disturbance began very indefinitely on January 30 at about 02h GMT, and ended equally indefinitely at about 10h, February 2. There were no outstanding features, the disturbance consisting chiefly of relatively shallow bays with a small amount of short-period activity superposed.

March 23-25—What later developed into one of the severest storms on record here began rather sharply at 06h 17m GMT, March 23, though it did not develop into a storm of any particular importance until 13h 30m, March 24. At that moment *H* suddenly increased 74 gammas, while east declination decreased about 10 minutes and *Z* was slightly disturbed. There was considerable activity from this point on, but the real storm began about two hours later, at 15h 45m. After that for about three hours the *D*- and *H*-traces are so confused that it is impossible to tell exactly what happened, but it appears that *H* increased at least 425 gammas within a very few minutes, and immediately decreased equally rapidly, the trace going off the sheet at the bottom. The reserve *H*-spot, which came on the sheet at the top, followed the regular spot down even more rapidly, and also went off at the bottom. The total downward plunge was at least 800 gammas, and probably a good deal more than that. For more than twenty minutes both spots either remained off the sheet or moved too rapidly to register. The *Z*-spot went off the sheet at the top; *D* oscillated very violently, but its trace is so confused with the *H*-traces that measurement is impossible.

At 19h the storm calmed somewhat, although there still was a good deal of short-period activity. At about 00h, March 25, the activity began to increase again and soon became very violent. This time the longer period waves were predominant and the traces are easily distinguishable, although the amplitudes were still very large. At 11h, March 25, the large amplitudes abruptly ceased, and five hours later the storm seemed to have ended. The measurable range of *D* was 58′. From 19h, March 25, to 07h, March 26, there was a fresh outburst of mild activity.

March 26-28—A moderate storm began gradually about 15h GMT, March 26, and ended about 06h, March 28. There were no large amplitudes or sudden starts, but the disturbance was somewhat irregular.

March 29-April 1—Preceded by a few hours of minor activity, a very severe storm began sharply at 16h 03m GMT, March 29. The movements were irregular, the long periods predominating. After twenty hours it quieted down considerably, though the elements continued somewhat disturbed. At 10h 42m, March 31, there was a fresh start, after which the activity was almost as great as at first. This lasted until about 17h, April 1.

JOHN HERSHBERGER, *Observer-in-Charge*

Huancayo Magnetic Observatory

January to March, 1940

(Latitude 12° 02′.7 S., longitude 75° 20′.4 or 5^h $01^m.4$ W. of Gr.)

January 3—There was a sudden commencement at 14^h 41^m GMT, January 3, which was followed by generally disturbed conditions through 24^h, January 3. Range: H, 625 gammas.

January 10—The interval from 13^h to 21^h GMT, January 10, was moderately disturbed. Range: H, 453 gammas.

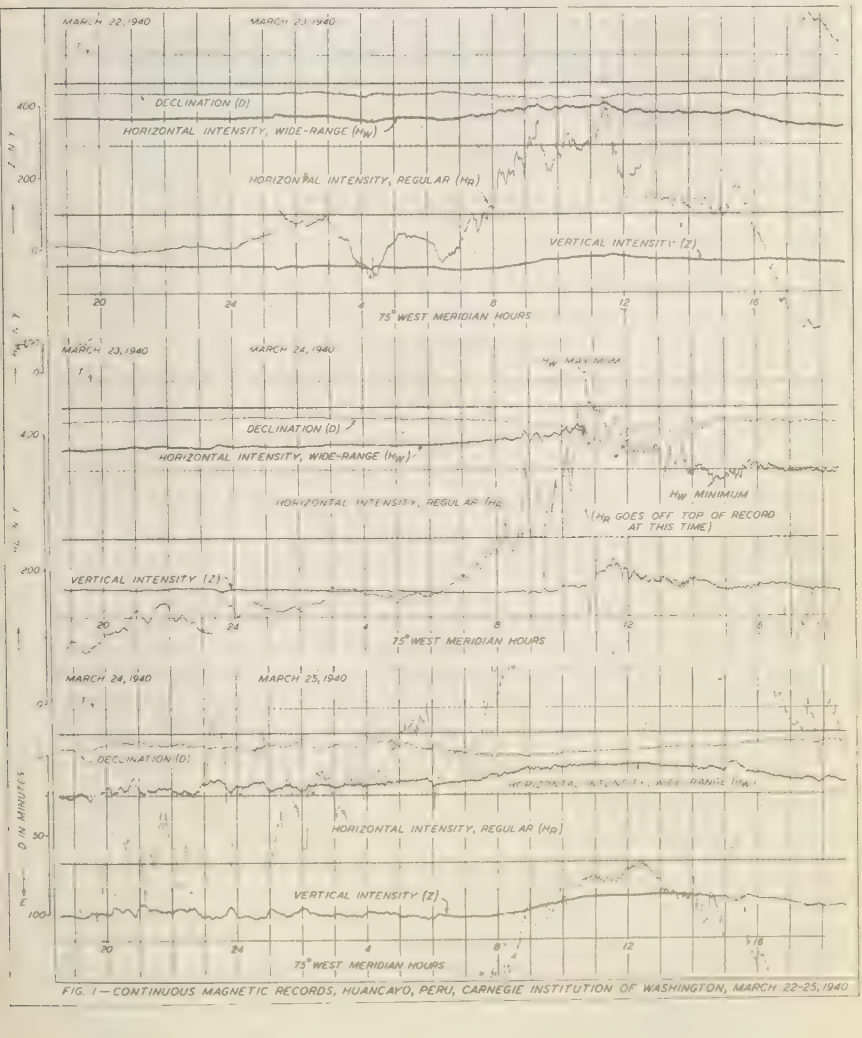

FIG. 1—CONTINUOUS MAGNETIC RECORDS, HUANCAYO, PERU, CARNEGIE INSTITUTION OF WASHINGTON, MARCH 22-25, 1940

January 18-19—The interval from 10^h GMT, January 18, to 03^h, January 19, was moderately disturbed.

February 17—There was a sharp increase in horizontal intensity at $18^h\ 35^m$ GMT, February 17, which was associated with a radio fade-out of moderate intensity.

February 24-25—There was a sudden commencement at $22^h\ 11^m$ GMT, February 24. Somewhat disturbed conditions followed which continued during the daylight hours of February 25.

March 23-26—There was a sudden commencement at $06^h\ 17^m$ GMT, March 23, which was followed by moderately disturbed conditions until

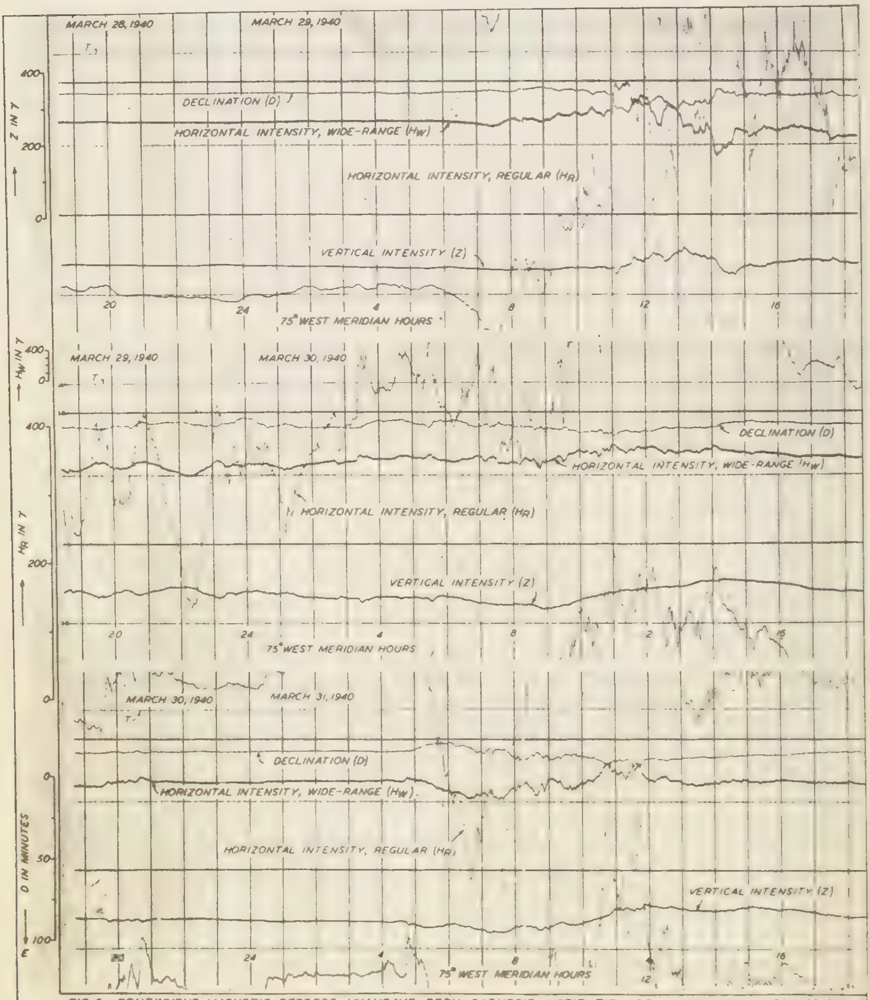

FIG. 2—CONTINUOUS MAGNETIC RECORDS, HUANCAYO, PERU, CARNEGIE INSTITUTION OF WASHINGTON, MARCH 28-31, 1940

13^h, March 24. The interval from 13^h, March 24 to 11^h, March 25, was violently disturbed. The period following until 12^h, March 26, was moderately disturbed, and the values of horizontal intensity were low. The range in H, on March 24, was 1395 gammas, which is the largest range that has been recorded at this Observatory since its beginning in 1922 (see Fig. 1).

March 29-April 1—A severe disturbance began at 12^h GMT, March 29, and the period until 19^h, March 30, was intensely disturbed. A moderately quiet period followed until 09^h 42^m, March 31, when what appears to be a sudden commencement occurred. The following interval through approximately 18^h, March 31, was very disturbed, and moderately disturbed conditions were recorded through about 21^h, April 1. The range in H on March 29 was 948 gammas (see Fig. 2).

H. W. WELLS, *Observer-in-Charge*

APIA OBSERVATORY

JANUARY TO MARCH, 1940

(*Latitude 13° 48′.4 S., longitude 171° 46′.5 or 11^h 27^m.1 W. of Gr.*)

March 23—A minor disturbance began at 06^h 15^m GMT, March 23 with a sudden increase in H of 21 gammas and in Z of 6 gammas. The H-trace then fell to a minimum at 09^h 22^m through a range of 81 gammas. The corresponding range of Z was 16 gammas. D was only slightly affected. The trace returned to normal level shortly after 10^h but small rapid oscillations continued.

March 24-26—Due to failure of clock the commencement of this disturbance was lost on the H- and D-records while the Z-trace was not recorded after 13^h 48^m GMT, March 24. From 21^h, March 24, until the minimum of this storm at 07^h 48^m, March 25, the H-trace was very disturbed with small rapid oscillations superposed on larger fluctuations. The value of the minimum was approximately 34550 gammas. The H-trace then rose rapidly by two steps to a value of approximately 34710 gammas at 09^h 17^m but fell again to a minimum of approximately 34606 gammas at 11^h 21^m before gradually returning towards normal although the disturbed period with depressed values continued throughout March 26. During the period of maximum disturbance the D-trace showed small rapid oscillations but between 04^h and 12^h, March 25, larger variations occurred; a decrease of 6′ in the easterly declination took place between 04^h 42^m and 05^h 00^m.

March 27—A sudden commencement of 9 gammas in H and 6 gammas in Z was recorded at 00^h 12^m GMT, March 27, and this was followed by a steady fall in H of 95 gammas to a minimum value at 03^h 26^m. The trace remained depressed and slightly disturbed during March 28 and 29. D was only very slightly affected.

March 29-30—An intense storm began at 16^h 05^m GMT, March 29, with a sudden increase in H of 14 gammas and in Z of 6 gammas then followed an irregular fall to the minimum for the storm at 04^h 54^m. The range in H was 269 gammas and during the same interval 23 gammas in Z. All elements were very disturbed till 14^h, March 30, and after this they slowly returned towards normal.

March 31—April 1—At 09^h 40^m GMT, March 31, a new storm com-

menced with a sudden increase in *H* of 58 gammas and in *Z* of 19 gammas. A maximum in *H* was recorded at $10^h\ 14^m$ after which the trace fell through a range of 163 gammas to a minimum at $13^h\ 02^m$; during this period the range in *Z* was 29 gammas. Two oscillations with a range of 31 gammas in *H* and 21 gammas in *Z* occurred between $12^h\ 10^m$ and $12^h\ 24^m$. Diminished activity continued until 12^h, April 1, and then the traces gradually returned towards normal. *D* was slightly disturbed.

H. Bruce Sapsford, *Acting Director*

Alibag Magnetic Observatory[1]

October to December, 1939

(Latitude 18° 38'.3 N; longitude 72° 52'.2 or $4^h\ 51^m.5$ E. of Gr.)

October 3-4—A moderate disturbance began at $00^h\ 01^m$ GMT, October 3, with a sudden commencement which was not large. *H* attained its minimum value at $17^h\ 16^m$, October 3. The disturbance ended at about $05^h.5$, October 4. Ranges: *D*, 4'.1; *H*, 108 gammas; *Z*, 27 gammas.

October 13-14—A storm of great intensity commenced at $02^h\ 03^m$ GMT, October 13, with a sudden rise of 2'.8 in westerly *D*, and 51 gammas in *H* and a fall of 26 gammas in *Z*. Rising with oscillations *H* attained its maximum at $04^h\ 20^m$ after which it began to fall with small-period oscillations. At $08^h\ 36^m$, October 13, there was a sudden rise of 29 gammas in *H* in three minutes followed by a rapid fall of 61 gammas in four minutes. The oscillations in *H* became less violent thereafter and continued so till 15^h, October 13, when conditions became once more disturbed. The minimum in *H* was reached at $21^h\ 52^m$, October 13, after which the force rose rapidly with oscillations. At about $23^h.5$, October 13, *H* began to fall again and the storm practically ended at $01^h.5$, October 14. Ranges: *D*, 10'.0; *H*, 314 gammas; *Z*, 62 gammas.

October 14-15—A fresh disturbance of moderate intensity began gradually at about $02^h.5$ GMT, October 14. After a period of slight activity, *H* began to show rapid fluctuations from 06^h, October 14. The minimum in *H* was attained at $12^h\ 25^m$, October 14. Thereafter the force began to rise with less violent fluctuations till 04^h, October 15, when a period of greater activity followed till $06^h.5$, October 15. The maximum in *H* occurred at $04^h\ 59^m$, October 15. The disturbance practically ended at $08^h.5$, October 15, though minor fluctuations continued for some time more. Ranges: *D*, 6'.9; *H*, 166 gammas; *Z*, 58 gammas.

November 13—A moderate disturbance commenced at about 04^h GMT, November 13. *H* attained its maximum at $04^h\ 17^m$ and the minimum at $11^h\ 54^m$. There was a conspicuous bay between $20^h.5$ and 22^h, after which the disturbance ended. Ranges: *D*, 3'.5; *H*, 175 gammas; *Z*, 37 gammas.

December 6-7—A moderate storm began gradually at about $20^h.5$ GMT, December 6. *H* reached its maximum at $08^h\ 18^m$, December 7, and the minimum at $17^h\ 33^m$, December 7. The disturbance practically

[1]Communicated by Dr. S. R. Savur, Director, Bombay and Alibag Observatories.

ended at 22^h, December 7. Ranges: D, 6'.3; H, 121 gammas; Z, 45 gammas.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
Bombay Observatory, India

M. R. RANGASWAMI

WATHEROO MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1940

(*Latitude 30° 19'.1 S., longitude 115° 52'.6 or 7^h 43^m.5 E. of Gr.*)

January 3—A short disturbance of moderate intensity began at 06^h 39^m GMT, January 3, with sharp movements in all three elements. Horizontal intensity increased by 15 gammas, declination moved easterly by rather less than 1', and the numerical value of vertical intensity decreased by 3 gammas. Following the sudden commencement there was a comparatively quiet period lasting almost exactly eight hours. At 14^h 40^m the horizontal intensity increased suddenly by 42 gammas while the other two elements barely showed a change. Wide fluctuations ensued shortly afterwards in all the elements, and lasted for about three hours, after which time the traces were only slightly disturbed until 24^h. Ranges: D, 14'; H, 185 gammas; Z, 94 gammas.

March 23-28—This disturbance, of major importance, began at 06^h 16^m GMT, March 23, with rather sudden movements in all three elements, H increasing by 27 gammas, the corresponding movements in Z and D being quite small. Apart from a brief period of activity between 09^h 10^m and 09^h 20^m on the same day, the traces were only moderately disturbed during the ensuing thirty hours; an interesting feature, however, was the increasing rapidity of the fluctuations, though of small amplitude, after 00^h, March 24. At 13^h 49^m, March 24, the main activity of the storm was heralded by a sudden commencement, where H increased by 55 gammas, the numerical value of Z decreased by about 7 gammas and the westerly declination decreased by about 2'. Thereafter the fluctuations became so violent that some of the movements were too rapid to record; it is probable, however, that the maximum intensity of the disturbance was at about 01^h, March 25, when the horizontal intensity reached a value about 500 gammas lower than the normal, this representing a decrease of over two per cent in the force. These rapid and violent fluctuations continued until about noon, March 25, after which the activity was very much reduced and without any noteworthy feature except for a pronounced "bay" at 19^h 30^m, March 26. Throughout March 27 and 28 the traces were slightly disturbed but were gradually resuming their normal values. The aurora was observed in and around Perth at intervals between 17^h and 20^h, March 24. Ranges: D, 45'; H, 685 gammas; Z indefinite, but greater than 300 gammas.

March 29-April 1—This disturbance, of more than moderate intensity, may probably be considered to be a later phase of the one which is described above and which subsided before 24^h GMT, March 28. There were signs of increasing activity in the curves after 09^h, March 29, with a prominent "bay" at 12^h 18^m. At 16^h 03^m, March 29, there appeared what would normally be considered a sudden commencement, H increasing very suddenly by 66 gammas. The next feature was a succession of "peaks" and "bays" between 17^h 39^m and 19^h 00^m on the

same day, during which the declination covered a range of 35′. During this time the value of *H* began to decrease and reached a minimum value at $04^h\ 37^m$, March 30, 355 gammas below the normal. The traces continued to be moderately disturbed through March 31 and it was not until 21^h, April 1, that they resumed their normal characters. Ranges: *D*, 51′; *H*, 365 gammas; *Z*, 271 gammas.

W. C. Parkinson, *Observer-in-Charge*

Capetown Magnetic Observatory

October to December, 1939

(Latitude 33° 57′ S., longitude 18° 28′ or $1^h\ 13^m.9$ E. of Gr.)

October 3-4—A storm began gradually at about $08^h\ 55^m$ GMT, October 3, and ended at 08^h, October 4. Conditions, however, remained somewhat disturbed until October 8. Ranges: *D*, 28′.2; *H*, 159 gammas; *Z*, 133 gammas.

October 8-9—A storm began with a small sudden commencement at $12^h\ 42^m$ GMT, October 8. Declination moved 5′ westerly from $07^h\ 00^m$ to $07^h\ 30^m$, 9′ easterly from $07^h\ 30^m$ to $08^h\ 10^m$ and 10′ westerly from $08^h\ 10^m$ to $09^h\ 30^m$. Horizontal intensity decreased 62 gammas from $06^h\ 00^m$ to $07^h\ 30^m$, increased 42 gammas from $07^h\ 30^m$ to $08^h\ 00^m$, decreased 62 gammas from $12^h\ 10^m$ to $13^h\ 20^m$ and increased 36 gammas from $13^h\ 20^m$ to $15^h\ 40^m$. The numerical value of vertical intensity increased 72 gammas from $05^h\ 45^m$ to $07^h\ 35^m$, decreased 64 gammas from $07^h\ 35^m$ to $08^h\ 10^m$, decreased 24 gammas from $11^h\ 50^m$ to $12^h\ 10^m$ and increased 56 gammas from $12^h\ 10^m$ to $13^h\ 20^m$. The storm was over at 16^h, October 9.

October 13-15—A storm began with a sudden commencement at $02^h\ 05^m$ GMT, October 13. Declination changed easterly for 4′ in four minutes. Horizontal intensity increased 62 gammas in three minutes, and the numerical value of vertical intensity diminished 32 gammas in five minutes. Over a period of twenty-five minutes at the beginning of the storm there were rapid variations which gradually subsided, but at 17^h declination changed westerly 20′ in sixty minutes. At $21^h\ 30^m$ the variations of declination were of the order of 17′ easterly and 17′ westerly in half-hourly periods. From $16^h\ 10^m$ to $17^h\ 45^m$ horizontal intensity diminished 105 gammas, and a numerical value of vertical intensity increased 120 gammas. At $22^h\ 35^m$ *H* increased 89 gammas in twenty minutes. From $22^h\ 05^m$ to $22^h\ 30^m$ the numerical value of *Z* diminished 88 gammas, increased 40 gammas to $22^h\ 40^m$ and diminished 88 gammas to $23^h\ 00^m$. The storm lasted until 18^h, October 15. Ranges: *D*, 32′; *H*, 253 gammas; *Z*, 171 gammas.

October 17-18—There were considerable disturbances on both days in the period from 16^h to 23^h.

November 13—There was a storm with a gradual commencement from 04^h to 20^h GMT, November 13. Ranges: *D*, 28′; *H*, 118 gammas; *Z*, 171 gammas.

December 6-7—A storm began gradually at 20^h GMT, December 6, and continued until 23^h, December 7. Ranges: *D*, 23′; *H*, 118 gammas; *Z*, 171 gammas.

Trigonometrical Survey Office, *Capetown, South Africa*

A. Ogg, *Magnetic-Survey Adviser*

NOTES

(See also page 212)

10. *Dedication of the McGregor Building of the University of Michigan*—On May 25, 1940, the new McGregor Building was formally presented to the University of Michigan. The principal address was given by Dr. Charles F. Kettering on "Frontiers of Research."

11. *Notes on magnetic survey of the United States*—Magnetic field-parties of the Coast and Geodetic Survey are now operating as follows: Howard S. Cole in southern and western United States; Joel B. Campbell in eastern United States; and Professor E. H. Bramhall along the arctic coast, Alaska. This will complete the repeat work for the isogonic maps of 1940.

The transfer of the variometers from the old variometer-building in Sitka to the temporary building at the new site was made on April 16 and 17, 1940. The transfer was completed in 37 hours. The absolute observations had to be discontinued at the old absolute building in September, 1939. They were resumed at the absolute building at the new site on January 9, 1940. However, the station-values had been carried to a monument on the new site by simultaneous observations prior to the discontinuance of the observations at the old absolute building. Preliminary examination shows that the continuity was quite good.

Since April 1, 1940, *K*-numbers have been compiled by all five observatories of the United States Coast and Geodetic Survey. A preliminary comparison with the records has been made, and the indications are that satisfactory values have been assigned but will require some revision before publication.

12. *Ionospheric work in the U. S. S. R.*—We learn from an article by F. Zaborshcikov in the Bulletin of the Academy of Sciences of the U. S. S. R., Geographical and Geophysical Series, No. 6, 1939, that there are three stations in the U. S. S. R. making observations on the ionosphere by means of radio waves, namely, Tomsk, Calm Bay (Franz Josef Land), and Slutzk (near Leningrad). These make use of the manual method with visual measurement of virtual heights on a scale which is on the screen of the cathode-ray oscillograph. The frequency-ranges over which these stations make observations are: Tomsk, 2 to 15 mc/sec; Calm Bay, 1.5 to 10 mc/sec; Slutzk, 1.5 to 15 mc/sec.

13. *Magnetic storm of March 24, 1940, and effects on communication- and power systems*—The unusually severe magnetic storm on Easter Sunday, March 24, 1940, disrupted telegraph- and cable-services and interrupted high-frequency radio communication over long distances, even affecting electric power-systems. Grounded telegraph-lines were rendered useless because of intense earth-currents induced by the violent magnetic fluctuations. Potentials as great as six volts per mile were induced at times and fluctuations of 1600 volts were observed on the 140-mile Western Union telegraph-line between New York and Binghamton, New York. The Consolidated Edison Company of New

York noted a dip of about 1500 volts on the 27-kilovolt busses at the Hudson Avenue Station in Brooklyn and also at the Hell Gate and Sherman Creek stations in the Bronx, the disturbance lasting for an hour or more.

This storm formed the basis of discussion at the Chicago meeting of the Edison Electric Institute on May 7, 1940. A detailed account of the storm and an analysis of its effects will appear in the September number of this Journal.

Very large ranges occurred at all magnetic stations: The Huancayo Magnetic Observatory experienced a range of approximately 1400 gammas in horizontal intensity, while at Niemegk the range amounted to about 2000 gammas in horizontal and nearly 1000 gammas in vertical intensity (see reproduction of wide-range magnetogram). Unusual displays of the aurora borealis were seen on the night of March 24,

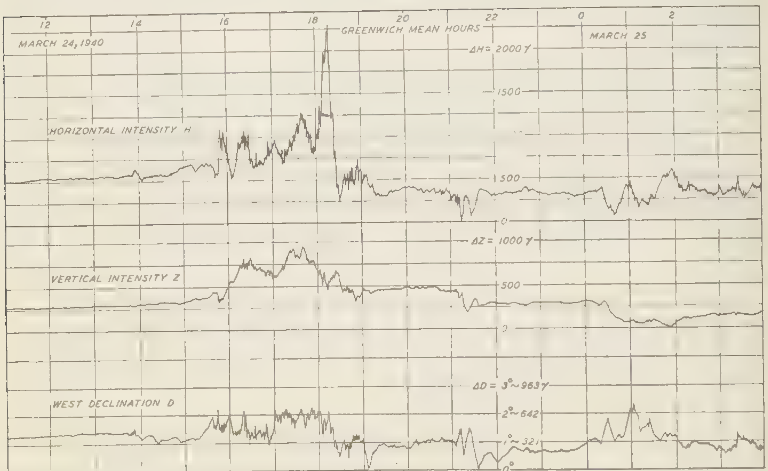

FIG. 1—WIDE-RANGE MAGNETOGRAM, POTSDAM-NIEMEGK, 11^h GMT MARCH 24 TO 4^h GMT MARCH 25, 1940 (AFTER G. FANSELAU)

some visible even as far south as Tucson, Arizona. Storms of much less intensity occurred on March 29-30 and March 30-31. Detailed descriptions for various observatories are given in the section "Principal Magnetic Storms" in this Journal.

14. *Solar eclipse of October 1, 1940*—The path of totality of the solar eclipse of October 1, 1940, begins at sunrise on the western coast of Ecuador, crosses the northern portion of the Continent of South America, the Atlantic Ocean, and the southern part of Africa, ending in the Indian Ocean. The opportunity to make ionospheric observations by radio methods on this occasion will be taken by the Huancayo Magnetic Observatory of the Carnegie Institution of Washington, which lies near the belt of totality, at sunrise and by the National Bureau of Standards in connection with the expedition of the National Geographic Society which will have a station observing towards noon at some point near Pernambuco, Brazil. Similar observations will also be made in South

Africa by an expedition, observing in the afternoon, which is sponsored by Harvard University in cooperation with the Bernard Price Institute of Geophysical Research of the University of the Witwatersrand, Johannesburg.

15. *Carter Observatory, Wellington, New Zealand*—By legislation in the New Zealand Parliament the Carter Observatory was established in 1939. It is financed by a bequest of the late Charles Rooking Carter and by grants from the Government and the Wellington City Council. The present director is M. Geddes. In addition to astronomical equipment, two auroral cameras, on loan from Professor Störmer of Oslo, are operated by voluntary observers in the South Island and a spectrohelioscope, on loan from the Mount Wilson Observatory, will be set up as soon as possible. It is intended to publish an Astronomical Bulletin monthly which will contain reports on the work, including auroral observations; in addition reprints of papers will be issued from time to time.

16. *Corrigenda*—In the March 1940 number of this JOURNAL in L. Vegard's article on page 5 in the third line of the last paragraph read "Figure 3 (spectrogram *B*3)" instead of "Figure 2 (spectrogram *B*1)" and on page 11 enter in box-head of second column of Table 4 "$20^h\ 50^m$ to $22^h\ 30^m$"; in T. L. Eckersley's article on page 27 in last line of second paragraph read "exactly 180° out of phase" instead of "exactly out of phase"; in article of F. W. G. White, C. J. Banwell, and G. A. Peddie on page 38 for sub-title of second last paragraph read "*Diurnal variation at Christchurch*", instead of "*Diurnal variation*", and on page 41 in title of Table 1 read "Christchurch" instead of "Wellington."

17. *Personalia*—Sir *George Simpson* is acting as Superintendent of the Kew Observatory, having returned temporarily from his retirement to the service of the Meteorological Office, on account of the war.

We regret to record the death at Leningrad, March 26, 1940, of the eminent Russian geographer, Professor *Jules Schokalsky*, at the age of eighty-four. After studying at the Naval School in St. Petersburg and serving as a midshipman in the Imperial Navy, he spent three years at the National Physical Observatory under the great meteorologist, H. Wild. He taught for many years at the Naval Academy, was librarian at the Cemtral Libray of the Russian Admiralty, and finally became a professor in the University of Leningrad. For many years he held the office of president of the Russian Geographical Society. Among his publications, which number nearly five hundred, the most important work is the "Treatise on oceanography," published in Russian in 1917. He is responsible for the publication of many atlases of the physical features of the U. S. S. R. He also completed a map of altitudes of the European part of the U. S. S. R. in six sheets on the scale of 1:2,500,000.

Captain *W. Benitez* has been appointed Director of the Observatorio de Marina, San Fernando, Spain, and of the Hydrographic Service of the Navy attached thereto, in succession of Admiral *León Herrero*, who retired in April 1940.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Alfvén, H. A theory of magnetic storms and of the auroras. Stockholm, Vet.-Ak. Handl., **18**, No. 3, 39 pp. (1939). [A neutral polarized stream of solar high-energy particles created near the sunspots and deflected by the magnetic fields of both the Sun and the Earth is considered in detail as the cause of magnetic storms.]

Antipolo Observatory. Results of the observations made at the Magnetic Observatory of Antipolo near Manila, P. I., during the calendar year 1938. (Part IV of the annual report of the Weather Bureau for the year 1938.) Manila, Bureau of Printing, 47 pp. (1938). 29 cm.

Comité National Français de Géodésie et Géophysique. Comité National Français et Comité National Marocain de Géodésie et Géophysique. Année 1938. Compte rendu publié par le Secrétaire Général du Comité Français, G. Perrier et le Secrétaire-adjoint, P. Tardi. Paris, Secrétariat Général du Comité Français, 148 pp. (1939). [Pp. 85-91 contain the report of the Section of Terrestrial Magnetism and Electricity.]

Copenhagen, Det Danske Meteorologiske Institut. Magnetisk aarbog. 1ste del; Danmark (undtagen Grönland)—Annuaire magnétique, lère Partie; le Danemark (excepté le Groenland). 1938. Köbenhavn, G. E. C. Gad, 37 pp. (1939). 32 cm.

Coulomb, J., J. Dubief, A. Lasserre, et P. Queney. L'enregistrement du champ magnétique terrestre à l'Observatoire de Tamanrasset. Ses résultats de 1934 à 1937. Paris, Ann. Inst. Phys. Globe, **17**, 67-113 (1939).

Dauvillier, A. Sur l' origine du magnétisme terrestre. Paris, C.-R. Acad. sci., **210**, 177-179 (1940).

De Bilt, Institut Météorologique Royal des Pays-Bas. Caractère magnétique de chaque jour des mois juillet-septembre 1939. De Bilt, 4 pp. (1939). 32 cm. [Published under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.]

Caractère magnétique numérique des jours. Tome XXXII. Juillet-septembre 1939. De Bilt, 27 pp. (1940). 24 cm. [Published under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.]

Eblé, L. Observations magnétiques faites à Chambon-la-Forêt pendant l'année 1937. Paris, Ann. Inst. Phys. Globe, **17**, 1-26 (1939).

Eblé, L., et G. Gibault. Valeurs des éléments magnétiques à l'Observatoire de Chambon-la-Forêt (Loiret) au 1er janvier 1940. Paris, C.-R. Acad. sci., **210**, No. 11, 409-410 (1940).

Ferri, F. La nuova carta magnetica d'Italia (isogone al 1° gennaio 1940) dell' Istituto Geografico Militare. Geofisica pura e applicata, Messina, **2**, No. 1, 12-19, 1 carta (1940).

Fleming, J. A. Terrestrial magnetism and electricity. American Year Book for 1939, 729-735 (1940). [New York, Thomas Nelson and Sons.]

Hirayama, M. On the Earth-magnetic change and Dellinger's effects of radio waves. Geophys. Mag., Tokyo, **13**, No. 2, 117-135 (1939).

Inglis, D. R., and E. Teller. Theory of terrestrial magnetism. Abstract, Phys. Rev., **57**, No. 6, 568 (Mar. 15, 1940). [Discussion and extension of the theory based on thermoelectric currents within the Earth, due to material convection guided by Coriolis forces.]

Jones, W. M. Magnetic observations of Nelson serpentines with remarks on the geology of the asbestos deposits. N. Z. J. Sci. Tech., Wellington, **21**, No. 3B, 128B-142B (1939).

KNAPP, D. G. Practical uses of the Earth's magnetism. Washington, D. C., U. S. Dept. Comm., Coast Geod. Surv., Ser. No. 618, 17 pp. (1939).

KUTSCHER, F. Magnetische Untersuchungen im Vulkanfelde der Bergfreiheitgrube von Schmiedeberg im Riesengebirge. Zs. prakt. Geol., **47**, Heft 4, 67-71 (1939).

LAHAYE, E. La déclinaison magnétique à Uccle en Décembre 1939. Ciel et Terre, **56**, No. 3, 123 (1940).

LARROQUE, J. Observations magnétiques en A. O. F. Paris, C.-R. Acad. sci., **210**, No. 6, 221-222 (1940). [Results of magnetic observations made at various stations in French West Africa during the last three years.]

LASAREFF, P. Sur les méthodes d' interprétation des mesures magnétiques dans le domain de l'anomalie magnétique de Koursk (1918-1927). Moskva, Bull. Acad. sci., Sér. Géog. Géophys., No, 3, 235-246 (1939). [Texte russe avec résumé français. L'auteur expose les méthodes employées par la Commission de l'Académie des Sciences de l'URSS pour décider si l'anomalie de Koursk est provoquée par le courant électrique souterrain ou si elle est produite par les gisements ferrugineux et il déduit des formules permettant de résoudre cette question et de démontrer d'après les données des levés magnétiques que l'anomalie de Koursk dépend des gisements. La seconde partie est consacrée à l'étude de la profondeur des gisements. Une des méthodes citées donne pour le maximum magnétique de Stschigry une profondeur entre 150 et 250 m. D'après les forages profonds cette profondeur est égale à 150 m.]

PARIS, INSTITUT DE PHYSIQUE DU GLOBE. Annales de l'Institut de Physique du Globe de l'Université de Paris et du Bureau Central de Magnétisme Terrestre. Publiées par les soins de Ch. Maurain. Tome XVII. Paris, Les Presses Universitaires de France, iii + 117 avec 5 pages de graphiques (1939).

POISSON, CH. Observations magnétiques faites à l'Observatoire de Tananarive (Madagascar) pendant l'année 1937. Paris, Ann. Inst. Phys. Globe, **17**, 64-66 (1939).

PRINCIPAL MAGNETIC STORMS. October to December, 1939. Terr. Mag., **45**, No. 1, 44, 48, 107-111 (1940). [Storms reported by Alibag Magnetic Observatory and by the Magnetic Observatory, Capetown, are for July to September, 1939.]

RAMANATHAN, K. R. The Earth's magnetism and the upper atmosphere. Proc. 26th Indian Sci. Cong., Lahore, 1939, Pt. 2, 19-43 (April 12, 1939). [Presidential address, Section of Mathematics and Physics.]

SIMPSON, K. W., AND A. M. VAN WYK. The quartz horizontal intensity magnetometer (Q. H. M.). Trans. R. Soc. S. Africa, **27**, Pt. 3, 223-224 (1939).

STONYHURST COLLEGE OBSERVATORY. Results of geophysical and solar observations, 1938. With report and notes of the Director, Rev. J. P. Rowland. Blackburn, Thomas Briggs, Ltd., xix + 40 (1939). 18 cm.

TABESSE, E. Observations magnétiques faites à l'Observatoire de Nantes pendant l'année 1937. Paris, Ann. Inst. Phys. Globe, **17**, 27-35 (1939).

ULRICH, W. Von der Unzulänglichkeit des Magnetkompasses. Seewart, **8**, 317-323 (1939).

VALLE, G., E G. TRIBULATO. Di un nuovo dispositivo magnetometrico a compensazione. Nuovo Cimento, **16**, No. 9, 441-446 (1939). [Gli A.A. descrivono l'apparecchio che ha servito loro per esaminare la possibilità di utilizzare un effetto di induzione provocato da un filo ferromagnetico percorso da una corrente alternata, per la misura della componente verticale del campo magnetico terrestre, in quanto che questo effetto scompare soltanto quando tale componente sia esattamente compensata con un campo magnetico ausiliario opposto. Le esperienze sinora eseguite hanno dimostrato che il metodo permetterebbe di raggiungere nelle misure la precisione di circa 10γ.]

WASSERFALL, K. F. On the variations of magnetic character-numbers at Dombås Observatory. Terr. Mag., **45**, No. 1, 1-4 (1940).

ZI-KA-WEI, OBSERVATOIRE DE. Observations magnétiques faites à la station de Zô-sè. Tome XXIII. Année 1938. Zi-ka-wei—Chang-hai, Imprimerie de la Mission Catholique, 42 pp. avec 2 feuilles de graphiques (1939). 31 cm.

B—Terrestrial and Cosmical Electricity

Aliverti, G., e G. Lovera. I fenomeni meteorologici sull' oceano e il campo elettrico terrestre. Estratto, Torino, Atti R. Acc. Sci., **74**, 20 pp. (1939).

Beardsley, N. F. Correlation between cosmic-ray intensity and upper air pressures and temperatures. Phys. Rev., **57**, No. 4, 336-337 (1940).

Bethe, H. A., S. A. Korff, and G. Placzek. On the interpretation of neutron measurements in cosmic radiation. Phys. Rev., **57**, No. 7, 573-587 (1940).

Bossolasco, M. Sulla prospezione geoelettrica dei vulcani. Geofisica pura e applicata, Messina, **2**, No. 1, 56-59 (1940). [Per la prospezione geoelettrica di un vulcano si illustra l'opportunità di far precedere un' indagine sulla distribuzione e sul comportamento delle relative correnti telluriche. Si osserva pure come le condizioni morfologiche dello Stromboli renderebbero agevole la registrazione delle correnti telluriche quali elementi revelatori diretti dell' attività del vulcano.]

Clayton, H. H. Auroras and sunspots. Terr. Mag., **45**, No. 1, 13-17 (1940).

Cocconi, G., e V. Tongiorgi. Sulla radiazione secondaria dei raggi cosmici. Nuovo Cimento, **16**, No. 9, 447-455 (1939).

Collins, O. C. Fireball of March 19, 1939, over Nebraska. Pop. Astr., **48**, No. 2, 65-69 (1940).

Dauzère, C. Sur la répartition géographique des points de chute de la foudre dans le département de l'Aveyron. Paris, C.-R. Acad. sci., **210**, No. 11, 442-444 (1940).

Dijk, G. van. Poollichtwaarnemingen Juni 1938—Februari 1939. Hemel en Dampkring, **37**, Afl. 3, 117-120 (1939).

Poollichtwaarnemingen in Februari 1939. Hemel en Dampkring, **37**, Afl. 5, 200-204 (1939).

Fritsch, V. Influenza delle condizioni geoelettriche sulla caduta del fulmine. Geofisica pura e applicata, Messina, **1**, No. 3/4, 175-216 (1939). [Richiamate le più importanti nozioni fondamentali sulla fisica del fulmine, si desume che i conduttori geologici da esso attaversati si comportano come se fossero percorsi da corrente alternata ad alta frequenza con una lunghezza d' onda dell' ordine de mille metri. Tenendo presente che le leggi della radiogeologia constituiscono le basi di ogni indagine relativa alla conduzione del fulmine nel sottosuolo, si giustifica il pericolo di caduta del fulmine per azione geoelettrica spiegandolo alla stregua dei dati d' osservazione. In pari tempo si dà ragione dell' esistenza dei cosidetti "nidi di fulmini." Rilevato come i dati statistici sinora raccolti risultino spesso non soddisfacenti, viene messa in luce l'utilità di una statistica organica e completa su tali fenomeni, illustrando l'opportunità dell' istituzione di appositi campi sperimentali per tutte le indagini referentesi ai fulmini nei rapporti con le caratteristiche geoelettriche del sottosuolo.]

Gerasimova, M. The atmospheric electricity measurements on Mt. Elbruz. Moskva, Bull. Acad. sci., Sér. Géog. Géophys., No. 4/5, 397-416 (1939). [Russian text with English summary.]

Herzog, G. Cloud-chamber photographs of cosmic rays up to an altitude of 29,300 feet. Phys. Rev., **57**, No. 4, 337 (1940).

Hughes, D. J. Positive excess and electron component in the cosmic-ray spectrum. Phys. Rev., **57**, No. 7, 592-597 (1940).

Jánossy, L., and P. Ingleby. Penetrating cosmic ray showers. Nature, **145**, 511-512 (Mar. 30, 1940).

Jánossy, L., and B. Rossi. On the photon component of cosmic radiation and its absorption coefficient. Proc. R. Soc., A, **175**, No. 960, 88-100 (1940).

Johnson, T. H., and J. G. Barry. The contributions of showers to the coincidences recorded at high elevations. Phys. Rev., **57**, 245-246 (Feb. 1, 1940).

Jones, H., and D. Hughes. A magnet and cloud chamber for cosmic rays. Rev. Sci. Instr., **11**, No. 3, 79-83 (1940).

Josephson, V., D. K. Froman, and J. C. Sterns. Simultaneous penetrating rays from the atmosphere. Phys. Rev., **57**, No. 4, 335 (1940).

LETTAU, H. Versuch einer Bilanz im Kondensationskern-Haushalt der Troposphäre im Durchschnitt für die ganze Erdoberfläche. Ann. Hydrogr., **67**, Heft 12, 551-559 (1939).

LEWIS, W. W., AND C. M. FOUST. Lightning investigations on transmission lines—VII. Elec. Eng. (AIEE Trans.), **59**, 227-232 (1940).

MAURAIN, CH., E. SALLES, M^me SALLES-HOMERY, G. GIBAULT, ET P. CHARCZENKO. Sur les phénomènes électriques terrestres à l'Observatoire du Val-Joyeux (d'après 12 années d'observations). Champ électrique, conductibilité, ionisation. Paris, Ann. Inst. Phys. Globe, **17**, 49-56 (1939).

MOLARD. Enregistrement de la conductibilité électrique de l'air à la Martinique. Ann. Phys. Globe France d'Outre-Mer, **6**, No. 35, 129-133, 137-141 (1939).

NISHINA, Y., Y. SEKIDO, H. SIMAMURA, AND H. ARAKAWA. Cosmic-ray intensities and air masses. Phys. Rev., **57**, No. 7, 663 (1940).

NOTO, H. Some studies on thunderstorms. Part IV. (The relation between the sign of the potential-gradient and that of the charge on rain and snowflakes.) Jap. J. Astr. Geophys., **17**, No. 1, 101-118 (1939).

OGASAHARA, K. The local variation of atmospheric potential-gradient measured at Taihoku, Formosa, Japan. Terr. Mag., **45**, No. 1, 53-68 (1940).

OPPENHEIMER, J. R., AND H. SNYDER. The production of soft secondaries by mesotrons. Phys. Rev., **57**, No. 2, 75-81 (1940).

OSLO, NORWEGISCHES METEOROLOGISCHES INSTITUT. Jahrbuch des Norwegischen Meteorologischen Instituts für 1938. Oslo, Gröndahl und Sohn, 1939 (xi + 135). 33 cm. [Contains values of the electrical potential-gradient and conductivity at the Aas Meteorological Observatory.]

PEKERIS, C. L. Direct method of interpretation in resistivity prospecting. Geophysics, **5**, No. 1, 31-42 (1940).

PETRUCCI, G. Le impurità contenute nell'aria (polveri, fumi, nuclei di condensazione, ecc.) in relazione alla carica negativa della Terre. Universo, Firenze, **20**, No. 12, 931-932 (1939).

Possibilità di applicazione dei metodi geoelettrici di prospezione alla registrazione dei movimenti del magma entro i condotti vulcanici. Geofisica pura e applicata, Messina, **2**, No. 1, 20-28 (1940).

ROSSI, B. Electrons arising from the disintegration of cosmic-ray mesotrons. Phys. Rev., **37**, No. 6, 469-471 (1940).

System of units for nuclear and cosmic-ray phenomena. Phys. Rev., **57**, No. 7, 660 (1940).

ROSSI, B., N. HILBERRY, AND J. B. HOAG. The variation of the hard component of cosmic rays with height and the disintegration of mesotrons. Phys. Rev., **37**, No. 6, 461-469 (1940).

ROUCH, J. Observations du champ électrique de l'atmosphère en mer dans l'Océan Atlantique et dans la Méditerranée. Paris, Ann. Inst. Phys. Globe, **17**, 57-63 (1939).

RYPDAL, B., AND L. VEGARD. The excitation functions of nitrogen bands and their bearing on auroral problems. Geofys. Pub., Oslo, **12**, No. 12, 20 pp., 3 pls. (1940).

TAKEUTI, T., UND S. HUZISAWA. Photographische Registrierung der Ultrastrahlung aus der Stratosphäre. Tokyo, Proc. Physico-Math. Soc., **22**, 145-146 (1940).

TORRESON, O. W. Comment on Professor Ogasahara's paper concerning the potential-gradient measurements at Taihoku, Formosa. Terr. Mag., **45**, No. 1, 69-70 (1940).

VEGARD, L. On some recently detected important variations within the auroral spectrum. Terr. Mag., **45**, 5-12 (1940).

WATAGHIN, G., M. D. DE SOUZA SANTOS, AND P. A. POMPEIA. Simultaneous penetrating particles in the cosmic radiation. II. Phys. Rev., **57**, No. 4, 339 (1940).

WILSON, A. H., AND F. BOOTH. Large cosmic ray showers and mesons. Nature, 145, 103-104 (Jan. 20, 1940).

C—Miscellaneous

Bannon, J., A. J. Higgs, D. F. Martyn, and G. H. Munro. The association of meteorological changes with variations of ionization in the F_2-region of the ionosphere. Proc. R. Soc., A. **174**, No. 958, 298-309 (1940).

Booker, H. G., and S. L. Seaton. Relation between actual and virtual ionospheric height. Phys. Rev., **57**, No. 2, 87-94 (1940).

Bradbury, N. E., and W. T. Sumerlin. Night-sky light and nocturnal *E*-layer ionization. Terr. Mag., **45**, No. 1, 19-24 (1940).

Brunner, W. Provisional sunspot-numbers for October to December, 1939. Terr. Mag., **45**, No. 1, 18 (1940).

Dijk, G. van. Aux directeurs des observatoires magnétiques, contribuants à la publication "Caractère magnétique numérique des jours." Terr. Mag., **45**, No. 1, 106 (1940).

Eckersley, T. L. On the existence of a biannual component in the F_2-layer ionization. Terr. Mag., **45**, No. 1, 25-36 (1940).

Fisher, J. W. An experimental device for computing magnetic and gravitational anomalies. Geophysics, **5**, No. 1, 22-30 (1940).

Fleming, J. A. Note regarding resolution No. 4, Washington Assembly, International Association of Terrestrial Magnetism and Electricity. Terr. Mag., **45**, No. 1, 106 (1940).

Gilliland, T. R., S. S. Kirby, and N. Smith. Characteristics of the ionosphere at Washington, D. C., November, 1939, with predictions for February, 1940. Proc. Inst. Radio Eng., **28**, No. 1, 40-41 (1940).

Characteristics of the ionosphere at Washington, D. C., December, 1939, with predictions for March, 1940. Proc. Inst. Radio Eng., **28**, No. 2, 91-92 (1940).

Harradon, H. D. The fourth centenary of William Gilbert of Colchester. Terr. Mag., **45**, No. 1, 97-98 (1940).

List of recent publications. Terr. Mag., **45**, No. 1, 113-119 (1940).

Johnston, H. F. American *URSI* broadcasts of cosmic data, with American magnetic character-figure C_A, October to December, 1939, and summary of C_A for the year 1939. Terr. Mag., **45**, No. 1, 99-104 (1940).

Laby, T. H., J. J. McNeill, F. G. Nicholls and A. F. B. Nickson. Wave-form, energy and reflexion by the ionosphere, of atmospherics. Proc. R. Soc., A, **174**, No. 957, 145-163 (1940).

Lazarev, P. P., N. I. Leuschin, N. N. Nikolsky, N. V. Pushkov, and N. N. Trubyatchinsky. Report on work in terrestrial magnetism and electricity in U.S.S.R. during 1936-1939. Terr. Mag., **45**, No. 1, 71-76 (1940).

Lejay, P. Etude de l'ionisation à Shanghai. Mesure du coefficient de reflexion des régions ionisées. Paris, C.-R. Acad. sci., **210**, No. 11, 381-385 (1940).

Macelwane, J. B. Padre Luis Rodés, S. J., 1881-1939. Terr. Mag., **45**, No. 1, 87-91 (1940).

MacGregor, C. J. The MacGregor Arctic Expedition to Etah, Greenland, July 1, 1937 to October 4, 1938. Mon. Weath. Rev., **67**, No. 10, 366-382 (1939). [The four main objectives of the Expedition were as follows: (1) To collect weather data from the Polar Basin, with special reference to the effects of conditions in the polar regions to the formation of polar air-masses and the weather of lower latitudes. (2) To make a magnetic survey for the Carnegie Institution of Washington. (3) To photograph the aurora borealis and study its effects on radio transmission. (4) To explore the Polar Basin northwest of Ellesmereland, Canada, in order to clear up the question of Crocker Land placed on the maps 30 years ago and which was found to be nonexistent. Only meteorological results are given in this article.]

Majorana, Q. La ionosfera. Nuovo Cimento, **16**, No. 9, 458-487 (1939).

Mount Wilson Observatory. Summary of Mount Wilson magnetic observations of sunspots for November and December, 1939. Pub. Astr. Soc. Pacific, **52**, 42-45 (1940).

National Bureau of Standards. Averages of critical frequencies and virtual heights of the ionosphere, observed by the National Bureau of Standards at Washington, D. C., October to December, 1939. Terr. Mag., **45**, No. 1, 98-99 (1940).

Nicholson, S. B., and E. S. Mulders. Provisional solar and magnetic character-figures, Mount Wilson Observatory, October to December, 1939. Terr. Mag., **45**, No. 1, 104-106 (1940).

Parkinson, W. C., and L. S. Prior. The ionosphere at Watheroo, Western Australia, July to September, 1939. Terr. Mag., **45**, No. 1, 45-47 (1940).

Perrier, G. La 7e assemblée générale de l'Union Géodésique et Géophysique Internationale, Washington, 3-15 septembre 1939. Paris, Bul. soc. astr. France, **54**, 30-34, 61-67 (1940).

Romañá, A. Le Rév. P. Louis Rodés, S. J. (1881-1939). Ciel et Terre, **56**, No. 2, 74-77 (1940).

Smith, N. Predictions of normal radio critical frequencies related to solar eclipses in 1940. J. Res. Bur. Stan., **24**, No. 2, 225-228 (1940).

Stetson, H. T. Auroras, radio field-strengths, and recent solar activity. Terr. Mag., **45**, No. 1, 77-86 (1940).

Störmer, C. Observations and photographic measurements of mother of pearl clouds over Scandinavia 1930-1938. First part. Geofys. Pub., Oslo, **12**, No. 11, 33 pp., 10 pls., 31 figs. (1939).

Wells, H. W. The ionosphere at Huancayo, Peru, July to September, 1939. Terr. Mag., **45**, No. 1, 49-52 (1940).

White, F. W., J. C. Banwell, and G. A. Peddie. Measurement of F_2-region ionization over New Zealand. Terr. Mag., **45**, No. 1, 37-43 (1940).

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THE THEORY OF THE FIRST PHASE OF A GEOMAGNETIC STORM

BY S. CHAPMAN AND V. C. A. FERRARO

Abstract—An exact solution is given (apart from the neglect of displacement-currents) for the motion and electromagnetic fields of a uniform neutral ionized distribution of ions and electrons initially situated on an indefinitely long circular cylindrical surface, and projected radially inwards towards the axis of the cylinder, in the presence of a permanent magnetic field which is everywhere parallel to the axis, and varies in intensity as the inverse cube of the distance from the axis. It is shown that the ions and electrons will remain "united," that is to say, will continue to lie on one cylindrical surface, if the total ionic (or electronic) charge exceeds a certain lower limit; an electric current will be induced, flowing round the cylindrical surface and increasing the magnetic intensity within the cylinder. The problem is discussed as one which partly illustrates the first phase of a magnetic storm, and, in particular, the sudden increase of H, during only a few minutes; it clearly shows that when a neutral ionizing stream advances into regions of increasing intensity in a magnetic field, the electrostatic attraction between the ions and electrons can carry the electrons forward far beyond the distances they could attain alone, if the stream is sufficiently dense.

1. INTRODUCTION

1. 1. *Purpose*—In this paper we attempt to clarify the first part of our theory of geomagnetic storms [see 1, 2 of "References" at end of paper]. In that theory we considered what events would follow the projection from the Sun, towards the Earth, of a neutral ionized stream of particles (ions and electrons).

The phenomena involved are on a scale outside ordinary knowledge and experience; the perception of the nature of the principal phases in their development depends initially on imagination and intuition, which must be followed by critical consideration of the numerous apparent possibilities, and later by careful quantitative discussion. Unfortunately the mathematical problems involved are complex, comprising a combination of hydrodynamics, electromagnetism, and gas-theory; we have seriously attacked only a few of them, with limited success. Much remains to be done before we could claim to have established our theory, though we know of no alternative theory that seems more promising.

In the present paper we confine our attention to the first phase of a geomagnetic storm, during which, for a few hours, the horizontal magnetic force, over the major part of the Earth, is raised above its normal value. The change is due mainly to an external magnetic field superposed on the normal field; but the growth of this external field induces

electric currents within the Earth, whose magnetic field nearly cancels the vertical component of the external field, and enhances the horizontal component. About two-thirds of the latter is due to the external field, which appears to be nearly uniform over the space occupied by the Earth; its direction is approximately northwards, parallel to the Earth's magnetic axis, and its intensity may be taken, in illustrative calculations, as 20γ for a moderate magnetic storm.

1. 2. *Outline of our theory*—A general description of our explanation of the origin of this external field is given in §6 of our original paper [1]; it will be summarized here. The field is attributed to a system of electric currents induced near the surface of the stream of solar gas, as it advances into the Earth's magnetic field. We compared this effect with the induction of current in an ordinary conductor when it is brought near a magnet; the currents are such as partly shield the interior of the body from the external field, which they partly neutralize, within the body, by their own field. The external field also exerts a mechanical force on the induced currents, which is equivalent to a repulsion hindering the approach of the body towards the magnet.

In this illustration, as in the case of the solar stream of gas advancing towards the field of the geomagnet, the repulsive force varies from point

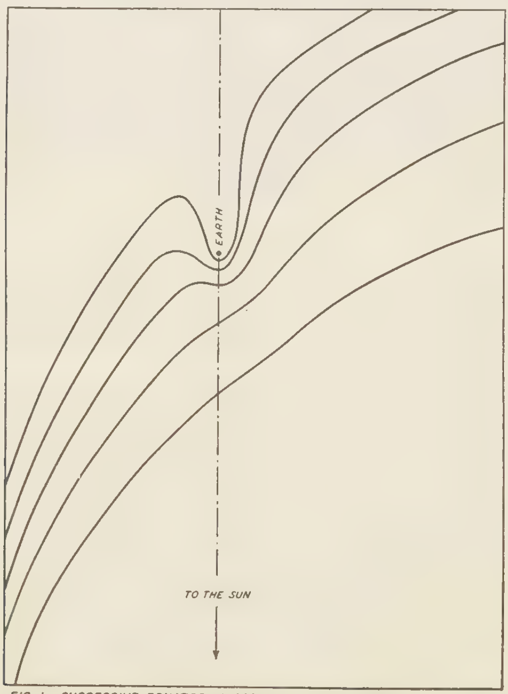


FIG. 1—SUCCESSIVE EQUATORIAL SECTIONS OF THE SURFACE OF ADVANCING STREAM

to point, being in general greatest at the points nearest the magnet. The stream of solar gas, unlike an ordinary metallic conductor, has no rigidity, so that the repulsion will depress the surface; the parts where the repulsion is less will advance relatively to those where it is greater. An open hollow is thus "carved" in the stream by the geomagnetic field; this is shown diagrammatically in Figure 1.

1. 3. *First illustrative problem*—In §§7.1-7.6 of [1] we illustrated some features of the first-phase phenomena (namely the current-system, the shielding of the space behind the current-system from the Earth's field, and the energy involved) by considering an idealized version of the phenomena. In this illustration we replaced the stream of solar gas by a thin *rigid plane* (perfectly) *conducting* (R.P.C.) sheet, parallel to the geomagnetic axis, and advancing along the direction normal to the plane; this drastic idealization of the problem enabled the above features to be discussed with fairly simple analysis. The retardation, the closeness of approach to the Earth, and the intensity of the first phase of the storm, were then considered in §§7.8, 9, and were found to depend mainly on the *kinetic-energy density* of the stream (near the Earth but before it is appreciably affected by the Earth's field). The intensity 20γ for the first-phase field corresponds to an approach of the conducting *plane* to within 7.5 Earth-radii from the Earth's center; for a neutral stream composed of singly ionized calcium atoms and electrons, moving with a velocity of 10^8 cm/sec or 1000 km/sec (before entering the Earth's field), the minimum undisturbed number density of the stream, outside the Earth's field, was estimated to be only of order 10.

1. 4. *Difficulties*—In §8 of [1] we considered the conductivity, thickness, and density of the retarded current-bearing layer of the stream, round the vertex of the hollow; in §9 we considered the variation of pressure, density, and temperature of this layer. In thus attempting to deal more closely with the actual nature of the stream, the simplicity of the results obtained in §7 for the above-mentioned idealized version of the problem became over-clouded with difficulties. In §8 we considered the reduction of the electrical conductivity (σ) of the current-bearing layer, in the direction transverse to the magnetic field, because of the deflecting influence of the field on the moving charges; the extent of the reduction of σ depends on the density, and it was supposed that this factor would control the thickness of the current-bearing layer and the intensity of its associated field; at the end of §9 doubt remained whether the density would permit σ to be as high as the theory seemed to require; it also did not seem certain that the electrons could advance far enough towards the Earth, the obstacle being the tendency of electrons (and to a less extent of ions) to "hook" themselves on to the lines of magnetic force.

1. 5. *One difficulty removed*—The main part of the present paper is devoted to the discussion of another idealized problem (the C.S. or cylindrical-shell problem), devised to throw light on one particular difficulty, namely, the "hooking" tendency. The conclusion arrived at is that this difficulty arose only because of an imperfect understanding of the motions of the charges during the first phase of the storm.

2. THE IDEALIZED CYLINDRICAL-SHELL PROBLEM (C.S.)

2. 1. *Features to be illustrated*—The problem here considered is designed to elucidate the retardation of the solar particles as they approach the Earth, and, particularly, the *relative* motions of the ions and electrons (which move together until the stream enters the Earth's field), and the resulting electric current. The subject of the problem is a system of particles, and not, as in the problem described in §1. 3, a plane rigid conducting sheet; in this respect the present problem more closely resembles the actual storm-problem. In order to facilitate the solution, however, we are forced to deviate from the actual storm-problem by drastic idealizations in other respects.

2. 2. *The idealized permanent field*—In the first place we substitute, for the actual geomagnetic field (which is a function of all three spherical polar coordinates r, θ, ϕ or cylindrical polar coordinates $\bar{\omega}$, ϕ, z), a unidirectional field which is a function of only one space coordinate: taking the z-axis along the direction of the field, and using cylindrical polar coordinates $\bar{\omega}$, ϕ, z, we suppose that the corresponding components $(H_{\bar{\omega}}, H_\phi, H_z)$ of the magnetic field $\mathbf{H}$ are as follows: $H_{\omega}=H_{\phi}=0$, $H=H_z$ (a function of $\bar{\omega}$ only).

Such a magnetic field could be produced by a solenoidal volume-distribution of electric current, whose current-intensity (in emu) has only a ϕ-component, c_ϕ, which is a function of $\bar{\omega}$ only. Any (infinitely long) cylindrical shell of such a current-distribution, of inner and outer radii $\bar{\omega}$, $(\bar{\omega}+\mathrm{d}\bar{\omega})$, carrying a current $c_\phi \mathrm{d}\bar{\omega}$ transverse to the generators, per unit-length along them, produces no magnetic field outside itself, and its field within the shell is uniform, and of intensity $4\pi c_\phi \mathrm{d}\bar{\omega}$. This is the change $\mathrm{d}H$ in the whole intensity of the field, as we cross the shell; hence

$$(\mathrm{d}H/\mathrm{d}\omega)=-4\pi c_\phi$$

which indicates the distribution of current-intensity required to set up any such field. Alternatively the field might be produced by a distribution of permanent magnetization $\mathbf{I}$ in the z-direction, such that

$$(\mathrm{d}H/\mathrm{d}\omega)=-4\pi I$$

In this case $\mathbf{H}$ must be interpreted as the magnetic *induction* in the polarized medium, usually written $\mathbf{B}$ $(=\mathbf{H}+4\pi\mathbf{I})$; $\mathbf{H}$ itself, in such a distribution of magnetization, is everywhere zero. In the remainder of this paper the $\mathbf{H}$ of the permanent field must be interpreted as signifying $\mathbf{B}$, if this field is supposed due to permanent magnetization: for example, the electric field on a charge moving in the magnetic field is $\mathbf{v}\wedge\mathbf{B}/c$, not $\mathbf{v}\wedge\mathbf{H}/c$ (§2. 6), and curl $\mathbf{A}=\mathbf{B}$, not $\mathbf{H}$ (§2. 7); though in the absence of magnetization the distinction between $\mathbf{H}$ and $\mathbf{B}$ vanishes.

We will suppose that for $\bar{\omega}>a$

$$H=H_0(a/\bar{\omega})^n \qquad \text{for } n>2$$

To illustrate the geomagnetic problem, we shall take a to equal the Earth's radius ($6{\cdot}37\times10^8$ cm), and $n=3$; also H_0 will be taken equal to the Earth's equatorial surface magnetic intensity ($0{\cdot}3\Gamma$), so that $H_0a^3=8\times10^{25}$ (the Earth's magnetic moment).

This field will be called the *permanent* magnetic field in our problem

(analogous to the Earth's field in the case of a magnetic storm). We suppose that the distributed current-system (or the distribution of permanent magnetization) which produces this field offers no mechanical resistance to the passage of particles (ions or electrons) through it, its only influence being due to the action of its magnetic field on moving charged particles. If the permanent field is supposed due to a current-system, it is necessary, in order to avoid other currents being set up in the current-carrying medium by any electric field which may arise during the "storm," to suppose that the permanent currents flow in a medium of vanishingly small conductivity σ, under the influence of correspondingly great electromotive forces; this would involve a great and continual loss of energy in overcoming the resistance, so that it is preferable to regard the permanent field as being due to a (completely pervious) distribution of permanent magnetization. It is easy to show that the magnetic vector-potential of this field has $\bar{\omega}$-, ϕ-, z-components 0, A, 0, where (for $\bar{\omega}>a$)

$$A=-H_0a^n/(n-2)\,\bar{\omega}^{(n-1)} \qquad \text{for } n>2$$

2. 3. *The system of particles* whose motion we consider, in the permanent field described in §2. 2, is also idealized so that it differs greatly from an actual solar stream.

In order to preserve the mathematical advantage of having only one effective variable of position ($\bar{\omega}$), we consider a system of particles which is uniform in the z-direction, and has symmetry about the axis of z; that is to say, it is independent of the z- and ϕ-coordinates. Further, instead of supposing the particles to be distributed in space over a long distance in the radial ($\bar{\omega}$) direction, as in the case of a solar stream, we postulate that at an instant which we take as our time-origin ($t=0$), all the particles are distributed (uniformly) over the surface of the cylinder $\bar{\omega}=\bar{\omega}_0$. In our numerical discussion we take $\bar{\omega}_0$ to be the distance between the Earth and Sun, $1{\cdot}5\times10^{13}$ cm or $1{\cdot}5\times10^{8}$ km.

2. 4. *Their initial motion*—We suppose that at the instant $t=0$ a velocity whose $\bar{\omega}$-, ϕ-, z-components (u, v, w) are $-u_0$, 0, 0 is suddenly imparted to every particle; that is to say, they are projected radially inwards towards the z-axis uniformly from all azimuths ϕ, instead of from only one direction (namely from the Sun) as in the case of a magnetic storm. In our numerical discussion we take u_0 to be 10^8 cm sec or 1000 km/sec, as we did in [1] for the particles of the solar stream.

The negative particles are supposed to be electrons, with the charge $-e$ ($e=4{\cdot}8\times10^{-10}$ esu) and the mass m_e ($=9\times10^{-28}$ gm); the positive particles (present in equal numbers) are supposed to be all alike, with a mass m_i ($=1{\cdot}6\times10^{-24}$ gm for H^+ ions, or $6{\cdot}4\times10^{-23}$ gm for Ca^+ ions), and a charge $\pm e$. Let $\pm Q$ (esu) be the amount of charge, of either sign, per unit-length of the cylinder $\bar{\omega}=\bar{\omega}_0$.

2. 5. *The electrostatic field* Let the subsequent velocity of a typical ion or electron at any later time t have the $\bar{\omega}$-, ϕ-, z-components u_i, v_i, w_i or u_e, v_e, w_e.

By virtue of the cylindrical symmetry of the system, the ions will always lie on a coaxial cylinder, say $\bar{\omega}=\bar{\omega}_i$, at the time t, and the electrons will similarly lie on a cylinder $\bar{\omega}=\bar{\omega}_e$.

If $\bar{\omega}_i\neq\bar{\omega}_e$, a radial electrostatic field will be set up in the space be-

tween the two cylinders (but not elsewhere); the $\bar{\omega}$-, ϕ-, z-components of the intensity of this field at a point $\bar{\omega}$ (between $\bar{\omega}_i$ and $\bar{\omega}_e$) will be $2Q'/\bar{\omega}$, 0, 0, independent of $\bar{\omega}_i$ and $\bar{\omega}_e$, and constant in time (so long as $\bar{\omega}$ remains between $\bar{\omega}_i$ and $\bar{\omega}_e$); Q' here denotes the charge per unit-length of the *inner* cylinder. The radial electrostatic force on an electron will be $-eQ'/\bar{\omega}_e$, and on an ion will be $eQ'/\bar{\omega}_i$; there is no additional factor 2, because half the electrostatic intensity at either surface $\bar{\omega}=\bar{\omega}_e$, $\bar{\omega}=\bar{\omega}_i$ arises from the immediately local charges.

This electrostatic field, and these radial forces on the charges, arise as soon as there is the slightest radial separation between the two sets of charges. Hence no radial separation will occur until the differential force tending to separate the two sets (while $\bar{\omega}_e$ and $\bar{\omega}_i$ are still equal) amounts to $eQ/\bar{\omega}$. Any smaller force tending to separate the two sets of charges will be neutralized without separation, just as a force tending to raise a body from a table remains without kinetic effect so long as it is less than the weight of the body.

2. 6. *The motions of the charges*—Each particle will move in a plane normal to the z-axis, because there is no force in the z-direction, so that the z-component of velocity is always $w=0$, since $w=0$ initially. Our problem is therefore one of plane motion, involving two solutions, one for each type of particle (Fig. 2). In this respect it is even simpler than the (general) Störmerian problem of a solitary charge moving in

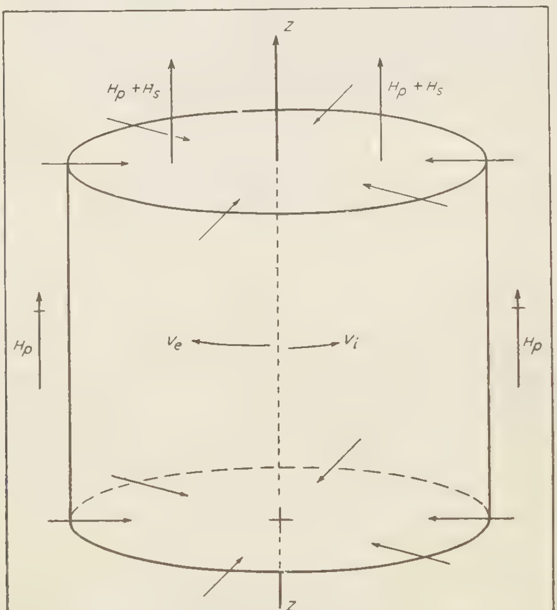


FIG. 2—CYLINDRICAL SHEET OF IONS AND ELECTRONS RADIALLY APPROACHING THE MAGNETIC AXIS (ZZ) OF THE PERMANENT MAGNETIC FIELD H_p (V_i, V_e INDICATE THE LATERAL MOTIONS OF THE PARTICLES)

a dipole magnetic field; but the two problems are widely different physically, because we consider the mutual electrostatic and electromagnetic influence of the two sets of particles, as well as the deflecting influence of the permanent field. Moreover on this account the two plane-motion solutions in our problem are interlocked, and this causes great mathematical difficulty if the ions and electrons become separated; fortunately these difficulties need not be faced for our purpose.

From the outset of the motion the electromagnetic deflecting force of the permanent field sets up an azimuthal component of motion, v, different for the two sets of charges, because of their very different masses. These motions constitute an azimuthal or solenoidal current-distribution, which makes a varying addition to the permanent magnetic field. This additional field will be unidirectional ($H=H_z$) like the permanent field.

Let $\mathbf{H}$ denote the intensity of the combined magnetic field, and $\mathbf{v}$ the (vector) velocity of a particle, so that the vector product $(\mathbf{v} \wedge \mathbf{H})/c$ denotes the electric deflecting field due to the motion of the charges in the field $\mathbf{H}$; the $\bar{\omega}$-, ϕ-, z-components of this product are

$$vH/c, \quad -uH/c, \quad 0$$

As soon as the action of the permanent field has set up azimuthal motions of the particles (v_e, v_i), the $\bar{\omega}$-component of the forces, v_eH/c, v_iH/c begins to modify the radial motion; this remains the same for the two sets of particles unless and until the difference between the radial forces on an ion and an electron becomes greater than the electrostatic force holding the two sets together (§2. 5).

2. 7. *The field-equations*—After the particles have been set in motion, the field is no longer static; it is therefore to be expressed in terms of the scalar and vector potentials V and $\mathbf{A}$, such that

$$\text{(1)} \qquad \mathbf{H}=\operatorname{curl}\mathbf{A}, \quad \mathbf{E}=-(\dot{\mathbf{A}}/c+\operatorname{grad} V)$$

$$\text{(2)} \qquad \operatorname{div}\mathbf{A}+\frac{1}{c}\frac{\partial V}{\partial t}=0$$

Since the currents are all in the $\pm\phi$-direction, $\mathbf{A}$ has no $\bar{\omega}$- or z-component, and its ϕ-component, A, is a function of $\bar{\omega}$ and t only. Hence

$$\text{(3)} \qquad \operatorname{div}\mathbf{A}=0$$

and therefore V is independent of t, being a function of $\bar{\omega}$ only, so long as no charged sheet sweeps across the point considered, and causes a discontinuous change in V. Hence also the above general equations reduce to

$$\text{(4)} \qquad H_{\bar{\omega}}=H_{\phi}=0, \quad H_z=H=\frac{1}{\bar{\omega}}\frac{\partial(\bar{\omega}A)}{\partial\bar{\omega}}=\frac{\partial A}{\partial\bar{\omega}}+\frac{A}{\bar{\omega}}$$

$$E_{\bar{\omega}}=-\frac{\partial V}{\partial\bar{\omega}}, \quad E_{\phi}=-\frac{1}{c}\frac{\partial A}{\partial t}, \quad E_z=0$$

We note that the varying magnetic field, due to the sheet-currents, introduces an azimuthal electric field-component E_{ϕ}.

Let the ionic and electronic current-intensities in the charged sheet

(or sheets, if the two sets of charges become separated) be denoted by c_i, c_e, per unit-length of the sheet, along the generators; clearly, in electromagnetic units

$$c_i = Qv_i/2\pi c\,\bar{\omega}_i, \quad c_e = -Qv_e/2\pi c\,\bar{\omega}_e$$

Let

$$A = A_p + A_i + A_e$$

where A_p is due to the permanent field (§2. 2), that is

$$A_p = -H_o a^n/(n-2)\,\bar{\omega}^{n-1} \quad \text{for } n>2$$

and A_i, A_e are due to the ionic and electronic currents. Let H_p, H_i, H_e be the corresponding parts of H, so that

$$H = H_p + H_i + H_e$$

where

$$H_p = H_o\left(\frac{a}{\bar{\omega}}\right)^n, \quad H_i = \frac{1}{\bar{\omega}}\,\frac{\partial(\bar{\omega}A_i)}{\partial\bar{\omega}}, \quad H_e = \frac{1}{\bar{\omega}}\,\frac{\partial(\bar{\omega}A_e)}{\partial\bar{\omega}}$$

Similarly let

$$E = E_i + E_e$$

where

$$E_i = -\frac{1}{c}\,\frac{\partial A_i}{\partial t}, \quad E_e = -\frac{1}{c}\,\frac{\partial A_e}{\partial t}$$

The vector-potential due to a current-distribution which is changing in intensity and location is $(1/c)$ times the retarded potential of the (vector) current-intensity **c**. Owing to the small velocities (of order 10^8 cm/sec or less) involved in the present problem, and the moderate distance, at any time during the period considered, between the two sets of charges (if they become separated), it is sufficient, when dealing with the influence of the field H_i on the electrons, or of the field H_e on the ions, to ignore the distinction between the retarded and the instantaneous potential. Hence

$$\begin{aligned} H_i &= 4\pi c_i, & A_i &= 2\pi\,\bar{\omega}c_i & &\text{for } \bar{\omega} < \bar{\omega}_i \\ H_i &= 0, & A_i &= 2\pi\,\bar{\omega}_i c^2{}_i/\bar{\omega} & &\text{for } \bar{\omega} > \bar{\omega}_i \end{aligned}$$

and similarly for A_e; where

$$c_i = \rho_i v_i/c, \quad c_e = \rho_e v_e/c$$

and ρ_i, ρ_e are the surface-densities of ionic and electronic charge; since

$$\rho_i = Q/2\pi\,\bar{\omega}_i, \qquad \rho_e = -Q/2\pi\,\bar{\omega}_e$$

we have

$$c_i = Qv_i/2\pi\,\bar{\omega}_i c, \quad c_e = -Qv_e/2\pi\,\bar{\omega}_e c$$

3. THE EQUATIONS OF MOTION, AND THEIR SOLUTION

3. 1. *The field-forces on the charges*—On crossing a charged sheet, $E_{\bar{\omega}}$ is discontinuous owing to the field of the local charges, which has opposite signs on the opposite sides. The effective value of $E_{\bar{\omega}}$ acting on a charge in a surface-distribution is the part due to the non-local

charges; this part is the mean of the values of $E_{\tilde{\omega}}$ on the two sides (§2. 5). On the ions the radial electric force is $eQ'/\tilde{\omega}_i$, and on the electrons, $-eQ'/\tilde{\omega}_e$, where $Q'=Q$ if the two sheets are separated (because, as we shall see in §3. 3, the inner sheet is the ionic one), and if not, $Q'<Q$.

Similarly the effective value of H_z acting on a charge is the mean of the two values on the two sides of the sheet in which the charge lies. This mean value will be indicated by adding an accent to H; thus, when the sheets are not separated, H' is $(H_p+H'_i+H'_e)$, and when they are separated, the appropriate value of H' for the ionic sheet is $(H_p+H'_i+H_e)$, and for the electronic sheet is $(H_p+H_i+H'_e)$. By §2. 7

$$H'_i=2\pi c_i=Qv_i/\tilde{\omega}_i c, \qquad H'_e=2\pi c_e=-Qv_e/\tilde{\omega}_e c$$
$$A'_i=2\pi\tilde{\omega}_i c_i=Qv_i/c, \qquad A'_e=2\pi\tilde{\omega}_e c_e=-Qv_e/c$$

Since A is continuous across a current-sheet, it is unnecessary to add the accent to A, except to indicate that it refers to the value at the sheet itself.

3. 2. *The equation of motion* for an ion is

$$m_i\frac{d}{dt}\mathbf{v}_i=e(\mathbf{E}'+\mathbf{v}_i\wedge\mathbf{H}'/c) \tag{1}$$

which has no z-component; its $\tilde{\omega}$- and ϕ-components are

$$m_i\left(\frac{du_i}{dt}-\frac{v_i^2}{\tilde{\omega}_i}\right)=e\frac{Q'_i}{\tilde{\omega}_i}+e\frac{v_i}{c}(H_p+H'_i+H_e) \tag{2}$$

and

$$\frac{m_i}{\tilde{\omega}_i}\frac{d(\tilde{\omega}_i v_i)}{dt}=-\frac{e}{c}\frac{\partial}{\partial t}(A'_i+A_e)-\frac{eu_i}{c}(H_p+H'_i+H_e) \tag{3}$$

Here d/dt is the rate of variation "following the particle," commonly denoted by the "mobile operator" D/Dt, given by

$$\frac{D}{Dt}=\frac{\partial}{\partial t}+(\mathbf{v}_i\cdot\text{grad}) \tag{4}$$

Since A is a function of $\tilde{\omega}$ and t only, and A_p is a function of $\tilde{\omega}$ only

$$\frac{D}{Dt}(A_p+A'_i+A_e)=\frac{\partial}{\partial t}(A'_i+A_e)+u_i\frac{\partial}{\partial\tilde{\omega}}(A_p+A'_i+A_e) \tag{5}$$
$$=\frac{\partial}{\partial t}(A'_i+A_e)-u_i(H_p+H'_i+H_e)-\frac{u_i}{\tilde{\omega}_i}(A_p+A'_i+A_e)$$

by 2.7 (4). Also since

$$u_i=\frac{d}{dt}\tilde{\omega}_i=\frac{D}{Dt}\tilde{\omega}_i \tag{6}$$

by combining (5, 6) with (3) we may transform the latter to

$$\frac{D}{Dt}\left\{m_i\tilde{\omega}_i v_i+\frac{e\tilde{\omega}_i}{c}(A_p+A'_i+A_e)\right\}=0 \tag{7}$$

Integrating (7) from the time $t=0$ (when $A'_i=A_e=0$, $v_i=0$, $\bar{\omega}_i=\bar{\omega}_o$) to the time t, we have

$$(8) \qquad m_i\bar{\omega}_i v_i+(e/c)\bar{\omega}_i(A_p+A_i+A_e)_i=(e/c)\bar{\omega}_o A_{po},$$

where A_{po} signifies the value of A_p at $\bar{\omega}=\bar{\omega}_o$ (§2. 2), and the other terms A refer to $\bar{\omega}=\bar{\omega}_i$, as indicated by the suffix i outside the parenthesis; the accent of A'_i has been dropped in accordance with §3. 1.

For the electrons the equations corresponding to (2, 8) are

$$(9) \qquad m_e\left(\dot{u}'_e-\frac{v_e^2}{\bar{\omega}_e}\right)=-\frac{eQ'}{\bar{\omega}_e}-\frac{ev_e}{c}(H_p+H_i+H'_e)$$

and

$$(10) \qquad m_e\bar{\omega}_e v_e-(e/c)\bar{\omega}_e(A_p+A_i+A_e)_e=-(e/c)\bar{\omega}_o A_{po}$$

3. 3. *The motion before separation*—At the time $t=0$, by hypothesis, $\bar{\omega}_i=\bar{\omega}_e=\bar{\omega}_o$, and $u_i=u_e=-u_o$; also $v_i=v_e=0$, $H_i=H_e=0$, $A_i=A_e=0$. The tendency for u_i to become different from u_e comes from the unequal action of the magnetic field on the ions and electrons once they have acquired transverse (azimuthal) motions by the deflecting action of the field; at first this tendency to unequal radial motion, and therefore to radial separation of the two sets of charges, will be weak, and easily resisted by the electrostatic attraction between them, represented by the terms $\pm eQ'/\bar{\omega}$ in §3.2 (2, 9). At the outset, therefore, $\bar{\omega}_i$ will continue to be equal to $\bar{\omega}_e$; we now show that during this stage of the motion Q' will steadily increase from the initial value zero to positive values; the positive sign indicates that the (positive) ions are drawing the electrons onward. When Q' attains the value Q, separation will begin, the ions advancing inwards towards the axis more rapidly than the electrons.

So long as $\bar{\omega}_i=\bar{\omega}_e=\bar{\omega}$, and therefore also $u_i=u_e=u$, the equations §3.2 (8, 10) are equivalent to

$$(1) \qquad m_i v_i=-m_e v_e$$

and

$$(2) \qquad m_e v_e=(e/c)\{A_p+A_i+A_e-(\bar{\omega}_o/\bar{\omega})A_{po}\}$$

and the equations 3.2 (2, 9) may be transformed to the equivalent forms

$$(3) \qquad (m_i+m_e)\dot{u}=(m_i v_i^2+m_e v_e^2)/\bar{\omega}+(e/c)(v_i-v_e)(H_p+H'_i+H'_e),$$

$$(4) \qquad Q'=\frac{m_i m_e}{m_i+m_e}\,\frac{v_e^2-v_i^2}{e}-\frac{\bar{\omega}(H_p+H'_i+H'_e)}{c}\,\frac{m_e v_i+m_i v_e}{m_i+m_e}$$

By means of (1) and (4) we may show that (3) is equivalent to

$$(5) \qquad \dot{u}=\frac{eQ'}{(m_i-m_e)\bar{\omega}}$$

By substitution in (2) for the various terms A, from §§2. 2, 3. 1, after some transformation we obtain the following expression for v_e as a function of $\bar{\omega}$

$$(6) \qquad -m_e v_e = \frac{ea^n H_0}{(n-2)c\bar{\omega}}\left(\frac{1}{\bar{\omega}^{n-2}} - \frac{1}{\bar{\omega}_0^{\,n-2}}\right) \Big/ \left(1 + \frac{eQ}{m'_e c^2}\right),$$

where

$$(7) \qquad m'_e = \frac{m_i m_e}{m_i + m_e}$$

By means of (6) we may convert (4) into the following expression for Q' as a function of $\bar{\omega}$

$$(8) \quad Q' = \frac{m_i - m_e}{m_i m_e} \frac{ea^{2n} H_0^2}{(n-2)^2 c^2 \bar{\omega}^2}\left(\frac{1}{\bar{\omega}^{n-2}} - \frac{1}{\bar{\omega}_0^{\,n-2}}\right)\left(\frac{n-1}{\bar{\omega}^{n-2}} - \frac{1}{\bar{\omega}_0^{\,n-2}}\right) \Big/ \left(1 + \frac{eQ}{m'_e c^2}\right)$$

Evidently $Q' = 0$ when $\bar{\omega} = \bar{\omega}_0$, and $Q' > 0$ when $\bar{\omega} < \bar{\omega}_0$. We may also note that if the negative charges had been negative ions of the same mass as the positive ions, so that $m_i = m_e$, Q' would always be zero, and the two sets of charges would never separate.

Since Q' is positive, it follows from (5) that $\dot{u}$ is also positive; this corresponds to retardation of the original motion. If the radial velocity is brought to rest before separation occurs, the radial motion will thereupon be reversed, and the particles will return to their original distance $\bar{\omega}_0$ (where their radial velocity will be $+u_0$) and go beyond it. During this return motion the azimuthal velocities v_i, v_e will have the same values, for any given value of $\bar{\omega}$, as during the inward motion (neglecting the small change in the energy of the system, by radiation).

3. 4. *The motion after separation*—If Q' increases to the maximum possible value Q, at a radial distance $\bar{\omega}_s$ given by $Q' = Q$, before the radial motion is brought to rest, separation will begin. The ions will at first travel beyond the electrons, so that $\bar{\omega}_i < \bar{\omega}_e$. During the separated motion we have four unknowns to determine, instead of (effectively) only two.

From 3. 2 (8, 10), after substituting for the terms A from §§2. 7, 3. 1, we obtain the equations

$$(1) \qquad \left(m_i + \frac{eQ}{c^2}\right) v_i - \frac{eQ}{c^2}\frac{\bar{\omega}_i}{\bar{\omega}_e} v_e = \frac{ea^n H_0}{(n-2)c\bar{\omega}_i}\left(\frac{1}{\bar{\omega}_i^{n-2}} - \frac{1}{\bar{\omega}_0^{\,n-2}}\right) \equiv h_i$$

$$(2) \qquad \left(m_e + \frac{eQ}{c^2}\right) v_e - \frac{eQ}{c^2}\frac{\bar{\omega}_i}{\bar{\omega}_e} v_i = -\frac{ea^n H_0}{(n-2)c\bar{\omega}_e}\left(\frac{1}{\bar{\omega}_e^{n-2}} - \frac{1}{\bar{\omega}_0^{\,n-2}}\right) \equiv -h_e$$

In these equations the addition of eQ/c^2 to m_i or m_e in the first term is due to A'_i or A'_e, that is, to self-induction in the ionic or the electronic current-sheet; (eQ/c^2) may be regarded as corresponding to an increase in the azimuthal inertia (resisting change of azimuthal velocity) of the particles. The second term in (1, 2) is due to the mutual induction of the two current-sheets.

By solving (1, 2) for v_i and v_e we find that

$$(3) \qquad (eQ/c^2)pv_i = (1 + m_e c^2/eQ)h_i - (\bar{\omega}_i/\bar{\omega}_e)h_e$$

$$(4) \qquad (eQ/c^2)pv_e = -(1 + m_i c^2/eQ)h_e + (\bar{\omega}_i/\bar{\omega}_e)h_i$$

where

$$(5) \qquad p \equiv \left(1 + \frac{m_i c^2}{eQ}\right)\left(1 + \frac{m_e c^2}{eQ}\right) - \left(\frac{\bar{\omega}_i}{\bar{\omega}_e}\right)^2$$

Since (for some time after separation) $\bar{\omega}_i < \bar{\omega}_e < \bar{\omega}_0$

$$(6) \qquad p > 0,\ h_i > h_e > 0$$

so that

$$(7) \qquad v_i > 0$$

but it is not possible to infer immediately from (4) whether or not v_e continues always to be negative, as it is before separation occurs; this depends on the ratio $\bar{\omega}_i/\bar{\omega}_e$, which is determined by the equations of radial motion 3. 2 (2, 9) with Q' replaced by Q; after substitution of the known values of v_i, v_e and H, these equations express $\dot{u}_i$ and $\dot{u}_e$ (or $\ddot{\bar{\omega}}_i$ and $\ddot{\bar{\omega}}_e$) in terms of $\bar{\omega}_i$ and $\bar{\omega}_e$; after writing $\dot{u}_i$ and $\dot{u}_e$ as $(\frac{1}{2}\mathrm{d}u_i^2/\mathrm{d}\bar{\omega}_i)$ and $(\frac{1}{2}\mathrm{d}u_e^2/\mathrm{d}\bar{\omega}_e)$, these equations can therefore be regarded as a pair of simultaneous differential equations of the first order, determining u_i^2 and u_e^2 as functions of $\bar{\omega}_i$ and $\bar{\omega}_e$. Obviously the solutions for u_i and u_e, and still more the solutions for $\bar{\omega}_i$ and $\bar{\omega}_e$ as functions of the time t, must be complicated.

In order to simplify the problem slightly, we shall now take $\bar{\omega}_0$ to be infinite, or, what is equivalent, we neglect $1/\bar{\omega}_0^{n-1}$ or $1/\bar{\omega}_0^{n-2}$ in 3. 3 (6, 8) and (1, 2); we must then suppose that $n > 2$. If we still reckon t from the time when $\bar{\omega} = \bar{\omega}_0$, the change affects the problem very slightly; u_i and u_e at $\bar{\omega} = \bar{\omega}_0$ will differ quite inappreciably from $-u_0$, and v_i and v_e will be extremely small there, because of the very low intensity of the permanent field at distances $\bar{\omega} > \bar{\omega}_0$.

3. 5. *The motion before separation* (*taking* $\bar{\omega}_0 = \infty$ and $n > 2$)—Besides taking $\bar{\omega}_0$ to be infinite, we make the further legitimate approximation of ignoring the difference between m_i and $(m_i \pm m_e)$, so that also m'_e becomes m_e. The equations for the period before separation occurs then reduce to the following: 3. 3 (1, 6) becomes

$$(1) \qquad m_i v_i = -m_e v_e = \frac{c m_e a^n H_0}{(n-2)\alpha_e Q}\,\frac{1}{\bar{\omega}^{n-1}} \text{ for } n > 2$$

where α_e, and an analogous quantity α_i, are defined by

$$(2) \qquad \alpha_e = 1 + \frac{m_e c^2}{eQ}, \quad \alpha_i = 1 + \frac{m_i c^2}{eQ}$$

Likewise 3. 3 (5, 8) become

$$(3) \qquad \dot{u} = \ddot{\bar{\omega}} = \tfrac{1}{2}\frac{\mathrm{d}u^2}{\mathrm{d}\bar{\omega}} = \frac{(n-1)ea^{2n}H_0^2}{(n-2)^2 m_i \alpha_e Q}\,\frac{1}{\bar{\omega}^{2n-1}}$$

and

$$(4) \qquad Q' = \frac{(n-1)a^{2n}H_0^2}{(n-2)^2\alpha_e Q}\,\frac{1}{\bar{\omega}^{2n-2}}$$

Hence the distance $\bar{\omega}_s$ at which separation begins is given by $Q' = Q$ or

$$(5) \qquad \left(\frac{\bar{\omega}_s}{a}\right)^{n-1} = \left(\frac{n-1}{\alpha_e}\right)^{1/2}\frac{aH_0}{(n-2)Q}$$

The magnetic field H'_s of the induced current is uniform within the

sheet, and from the above equations, together with §2. 7, it is readily shown that

$$(6) \qquad H_s/H_p = 2/(n-2)\alpha_e$$

where H_p is the intensity of the permanent field at the current-sheet; the field H_s is due almost entirely to the electronic motions, since the ions contribute only a fraction (m_e/m_i) of the electronic current. The field H_s represents, in this illustrative problem, the field of the first phase of a magnetic storm, and (H_s/H_p) is positive, as in the case of a real storm.

Outside the current-sheet the value of H_s is zero; in this respect the present problem does not illustrate the probable conditions in a real storm, in that (owing to the special property of a solenoidal current-system) there is no magnetic shielding of the space "behind" the current-sheet: the permanent field there remains unaffected by the induced currents.

A first integral of (3) can be obtained, in the alternative forms

$$(7) \qquad \left(\frac{u}{u_0}\right)^2 = 1 - \frac{ea^{2n}H_0^2}{(n-2)^2\alpha_e m_i Q u_0^2}\,\frac{1}{\bar{\omega}^{2n-2}}$$
$$= 1 - \frac{eQ}{(n-1)m_i u_0^2}\left(\frac{\bar{\omega}_s}{\bar{\omega}}\right)^{2n-2}$$

Hence the radial motion will be brought to rest and reversed, without separation of the two sets of charges, if

$$(8) \qquad Q > (n-1)m_i u_0^2/e$$

because if this inequality is satisfied, u becomes zero before $\bar{\omega}$ is reduced to $\bar{\omega}_s$; the minimum distance from the axis (ω_r, say) at which the radial motion is brought to rest, when (8) is satisfied, is given by

$$(9) \qquad \left(\frac{\bar{\omega}_r}{\bar{\omega}_s}\right)^{2n-2} = \frac{eQ}{(n-1)m_i u_0^2} > 1$$

or

$$(9a) \qquad \left(\frac{\bar{\omega}_r}{a}\right)^{n-1} = \frac{aH_0}{(n-2)u_0}\left(\frac{e}{\alpha_e m_i Q}\right)^{1/2}$$

and in terms of $\bar{\omega}_r$ we may replace (7) by

$$(10) \qquad \frac{u^2}{u_0^2} = 1 - \left(\frac{\bar{\omega}_r}{\bar{\omega}}\right)^{2n-2}$$

Let

$$(11) \qquad y = \bar{\omega}_r/\bar{\omega} < 1$$

and let t be the actual time of travel of the unseparated sheet of charges from $\bar{\omega} = \bar{\omega}_0$ to any distance $\bar{\omega}$ for which $y < 1$; also let t' be the time $(\bar{\omega}_0 - \bar{\omega})/u_0$ which would be taken by an uncharged sheet to traverse the same distance, with the constant velocity u_0. The time-difference $(t-t')$, which is positive because of the retardation of the ionized sheet, will be called the time-lag up to the distance $\bar{\omega}$. It depends very little on the

value of $\bar{\omega}_o$, if this exceeds the value mentioned in §2. 3, so that we shall take $\bar{\omega}_o = \infty$ as hitherto in the present section. It may readily be inferred from (10) that

$$(12) \qquad (t-t') = (\bar{\omega}_r/u_o) I_n(y)$$

where

$$(13) \qquad I_n(y) = \int^y \frac{1}{y^2} \left\{ \frac{1}{\sqrt{(1-y^{2n-2})}} - 1 \right\} dy$$

If $\bar{\omega}_o$ were finite, the lower limit zero in this integral would be replaced by $y_o (= \bar{\omega}_t / \bar{\omega}_o)$. The whole time-lag up to the distance $\bar{\omega}_r$ at which the radial motion is reduced to zero (at the time t_r) provided that separation does not occur before this point, is given by

$$(14) \qquad (t_r - t'_r) = \frac{\bar{\omega}_r}{u_o} I_n(1)$$

It is easy to show that when $n > 2$

$$(15) \qquad I_{n+1}(y) = \frac{1}{n 2^{1/n}} \int_o^u \frac{d\sigma}{\sigma^{1/2n}(1-\sigma)^{1+1/2n}}$$

where

$$(16) \qquad 2u = 1 - (1-y^{2n})^{1/2}$$

so that $u = 0$ when $y = 0$, and $u = \frac{1}{2}$ when $y = 1$. The integrand in (15) can be expanded in a series of powers of σ, convergent when $u \leqslant k < 1$.

When $n > 2$ and y is small, this gives

$$(17) \qquad (t-t') = \tfrac{1}{2} \frac{\bar{\omega}_r^{2n-2}}{(2n-3) u_o \bar{\omega}^{n-3}} \qquad (\bar{\omega} \text{ large}, n > 2)$$

When $n > 2$

$$(18) \qquad I_{n+1}(y) < I_n(y) \qquad (n > 2)$$

and from the expansion derived from (15) it is easy to show that

$$(19) \qquad I_3(1) = 0{\cdot}401$$

Incidentally it is easy to show directly from (13) that

$$(20) \qquad I_2(1) = 1$$

We may also note that at the instant of separation, when $\bar{\omega} = \bar{\omega}_s$, (3) and (5) indicate that

$$(21) \qquad \dot{u}_s = \frac{eQ}{m_t \bar{\omega}_s}$$

3. 6. *The motion after separation* (*taking* $\bar{\omega}_o = \infty$, $n > 2$)—Making the same simplifications as in 3. 5 (1), namely taking $\bar{\omega}_o = \infty$, $n > 2$, $(m_t \pm m_e) = m_t$, $m'_e = m_e$, we obtain the following equations for the motion after separation has begun: 3. 4 (3, 4) become

$$(1) \qquad v_t = \frac{ca^n H_o}{(n-2)pQ} \left(\frac{a_e}{\bar{\omega}_t^{n-1}} - \frac{\bar{\omega}_t}{\bar{\omega}_e^{n}} \right)$$

$$(2) \qquad v_e = - \frac{ca^n H_o}{(n-2)pQ} \left(\frac{a_t}{\bar{\omega}_e^{n-1}} - \frac{1}{\bar{\omega}_e \bar{\omega}_t^{n-2}} \right)$$

for $n > 2$

These values are equal to those given by 3. 5 (1) when $\bar{\omega}_i = \bar{\omega}_e = \bar{\omega}_s$.

When the separation begins, v_i is positive and v_e is negative, and $(v_i/v_e) = -(m_e/m_i)$. The condition that v_i shall remain positive is

$$(3) \qquad \left(\frac{\bar{\omega}_i}{\bar{\omega}_e}\right)^n < a_e \qquad (v_i > 0)$$

and the condition that v_e shall remain negative is

$$(4) \qquad \left(\frac{\bar{\omega}_e}{\bar{\omega}_i}\right)^{n-2} < a_i \qquad (v_e < 0)$$

The condition (3) is evidently satisfied, since $a_e > 1$, so long as $\bar{\omega}_i < \bar{\omega}_e$, which is certainly true when separation first begins.

The condition (4) shows that if the lag of the electrons becomes sufficiently great, v_e can become positive.

The equations of radial motion are as follows, so long as $\bar{\omega}_e > \bar{\omega}_i$

$$(5) \qquad m_i u_i = \frac{eQ}{\bar{\omega}_i} + \frac{eQ}{c^2}\left(\frac{a_i v_i^2}{\bar{\omega}_i} - \frac{2 v_e v_i}{\bar{\omega}_e}\right) + \frac{e v_i H_p}{c}$$

and

$$(6) \qquad m_e \dot{u}_e = -\frac{eQ}{\bar{\omega}_e} + \frac{eQ}{c^2}\,\frac{a_e v_e^2}{\bar{\omega}_e} - \frac{e v_e H_p}{c}$$

At the instant of separation, the common retardation $\dot{u}$ during the previous united radial motion had just attained the value $(eQ\ m_i\bar{\omega}_s)$, by §3. 5 (21). It is readily shown that in (5), just after the separation, the last three terms on the right (counting both terms in the bracket) are all positive, and their sum is approximately $(m_e\ m_i)$ times the first term. In (6) the last two terms on the right, just after the separation, are both positive, and slightly exceed the first term, approximately in the ratio $(1 + m_e\ m_i)$. Hence (5) and (6) agree approximately with §3. 5 (21) just after the separation. Subsequently, however, the motion may be complicated and difficult to discuss mathematically (cf. §6. 2).

4. NUMERICAL DISCUSSION OF THE PROBLEM

4. 1. *The condition that* $\bar{\omega}_r > \bar{\omega}_s$ –In the preceding discussion it has been shown that at first the two groups of charges, set in motion, as described in §§2.3, 4, in the presence of the permanent field (§2. 2), will move together; in the later motion two possibilities arise. The two sets of charges may *either* attain to a certain distance ($\bar{\omega}_s$) from the z-axis of the permanent field, and then separate the ions (at first) going ahead and the electrons lagging behind: *or* while they still remain together, the radial motion of the two sets of charges may be brought to rest, at a distance $\bar{\omega}_r$; if this happens, that is to say, if $\bar{\omega}_r > \bar{\omega}_s$, the charges will always remain together; after attaining their minimum distance $\bar{\omega}_r$ from the axis of the field, their motion will be reversed and the charges will retrace their paths.

It is obviously important, in the consideration of this problem, to determine what conditions decide whether or not the charges shall become separated. This is indicated by §3. 5 (9): the condition for no separation, $\bar{\omega}_r > \bar{\omega}_s$, is

$$(1) \qquad Q > (n-1) m_i u_0^2 / e$$

In our numerical discussion we shall take n to be 3, implying that the permanent field varies inversely as the cube of the distance from the axis (§2. 2); hence (1) becomes

$$(2) \qquad Q > 2m_i u_o^2/e$$

This condition, it may be noted, is independent of the *intensity* of the field; it depends only on the *law of variation* of the magnetic intensity with distance, as expressed by the factor $(n-1)$ in (1).

The condition requires that Q, the amount of positive charge per unit-length of the system of particles (in the z-direction), shall exceed a certain lower limit, which is proportional to the initial kinetic energy per positive particle (or per pair of particles, since in §3. 5 we have treated $(m_i \pm m_e)$ as equal to m_i); the greater the kinetic energy of an ion, the greater must Q be. This is because the electrostatic field which (if it is sufficiently intense) holds the two sets of particles together by their mutual attraction, is proportional to Q, while the opposing electromagnetic deflecting forces on the opposite charges depend on the speed of the particles.

If, as supposed in §2. 4, $u_o = 10^8$ cm/sec, and the ions are (a) hydrogen atoms H^+ or (b) calcium atoms Ca^+, the condition (2), expressed in terms of the number ν of ions per unit-length of the system, so that

$$(3) \qquad Q = \nu e$$

becomes

$$(4) \qquad \nu > 2m_i u_o^2/e^2 = 1{\cdot}4 \times 10^{11} \quad (H^+ \text{ ions}) \quad \text{or } 5{\cdot}6 \times 10^{12} \quad (Ca^+ \text{ ions})$$

In terms of Q, (4) is equivalent to

$$(5) \qquad Q > 67\text{esu} \quad (H^+ \text{ ions}) \quad \text{or } 2700 \quad (Ca^+ \text{ ions})$$

4. 2. *The self-induction mass-ratios for the ions and electrons*—In §3. 4 it was pointed out that the self-induction of the ionic and electronic sheets of induced current has the effect of increasing the inertial resistance of the two types of particle, for changes in their azimuthal, current-carrying velocity. The *self-induction mass-ratio* of this increase is $(eQ/m_i c^2)$ for the ions, and $(eQ/m_e c^2)$ (much greater) for the electrons. These ratios may be expressed in terms of the numbers α_i, α_e defined by §3.5 (2), being $1/(\alpha_i - 1)$ and $1/(\alpha_e - 1)$, respectively.

The no-separation condition of §4.1 can also be expressed in terms of the self-induction mass-ratio, since §4.1 (2) is equivalent to

$$(1) \qquad \frac{eQ}{m_i c^2} > 2\left(\frac{u_o}{c}\right)^2, \qquad \frac{eQ}{m_e c^2} > 2\frac{m_i}{m_e}\left(\frac{u_o}{c}\right)^2$$

If $u_o = 10^8$ cm/sec, these take the form

$$(2) \qquad \frac{eQ}{m_i c^2} > 2{\cdot}2 \times 10^{-5}, \qquad \frac{eQ}{m_e c^2} > 4 \times 10^{-2} \quad (H^+ \text{ ions}) \quad \text{or } 1{\cdot}6 \quad (Ca^+ \text{ ions})$$

Hence if the self-induction mass-ratio for the ions is greater than $2{\cdot}2\times 10^{-5}$, or if that for the electrons exceeds $0{\cdot}04$ or $1{\cdot}6$ (according as the positive ions are hydrogen or calcium atoms), the charges will not become separated.

When expressed in terms of α_i and α_e, the no-separation condition (with the above numerical data) is

$$(3) \qquad \alpha_i < 4{\cdot}5\times 10^4, \quad \alpha_e < 26 \quad (H^+ \text{ ions}) \qquad \text{or } 1{\cdot}6 \quad (Ca^+ \text{ ions})$$

The no-separation condition may also be expressed in terms of the factor p defined by §3. 4 (5), taking $\bar{\omega}_i = \bar{\omega}_e$ in this equation, because the charges are not separated; hence

$$(4) \qquad p = \alpha_i + \alpha_e + \alpha_i\alpha_e < 1{\cdot}3\times 10^6 \quad (H^+ \text{ ions}) \qquad \text{or } 7{\cdot}2\times 10^4 \quad (Ca^+ \text{ ions})$$

4. 3. *The minimum distance* $\bar{\omega}_r$—Assuming that the system of particles is sufficiently "dense" to satisfy §4. 1 (4), and its equivalent forms in §4. 2, we consider the numerical value of $\bar{\omega}_r$, the minimum distance of the particles from the magnetic axis; this is given by §3. 5 (9a), in terms of the distance a at which the intensity of the permanent magnetic field attains the value H_o. It is convenient to reckon $\bar{\omega}_r$ in terms of a as unit, or, what is equivalent, to consider $(\bar{\omega}_r, a)$, as in §3.5 (9a); when we take n to be 3, this gives, after substituting for α_e from §3.5 (2)

$$(1) \qquad \frac{\bar{\omega}_r}{a} = (aH_o)^{1/2} \left\{ \frac{e}{m_i u_o^2 (Q + m_e c^2/e)} \right\}^{1/4}$$

Since $(m_e c^2/e) = 1700$, its addition to Q in (1) is important, when Q is near its lower limit for no separation, if the ions are H^+ (when $Q > 67$) but much less so if the ions are Ca^+ (when $Q > 2700$).

We see from (1) that the distance of closest approach decreases as $u_o^{-1/2}$ if the speed of the particles is increased: for example, if the speed is doubled $(\bar{\omega}_r/a)$ is decreased in the ratio $0{\cdot}71$ or by 29 per cent; $(\bar{\omega}_r/a)$ also decreases if the stream-density is increased, but its dependence on this factor is only as $(Q+1700)^{-1/4}$.

Inserting in (1) the numerical values already given for a, H_o (§2. 2) and u_o, we have

$$(2) \qquad \frac{\bar{\omega}_r}{a} = \frac{5{\cdot}7\times 10^3}{(Q+1700)^{1/4}} \quad (H^+ \text{ ions}) \qquad \text{or } \frac{2{\cdot}3\times 10^3}{(Q+1700)^{1/4}} \quad (Ca^+ \text{ ions})$$

Inserting the minimum values of Q for these two cases, from §4. 1 (5), we infer that if no separation of the charges occurs

$$(3) \qquad (\bar{\omega}_r/a) < 890 \quad (H^+ \text{ ions}) \qquad \text{or } 280 \quad (Ca^+ \text{ ions})$$

That is to say, if Q is insufficient to bring the charges to these distances, the two sets of charges will become separated $(\bar{\omega}_s > \bar{\omega}_r)$.

4. 4. *The maximum magnetic disturbance* –The magnetic field of the induced currents, so long as the two sets of charges are not separated, is given by §3. 5 (6); this is greatest when the current-sheet attains its minimum distance $\bar{\omega}_r$; at that time (when $n=3$)

$$(1) \qquad H_s = \frac{2H_o}{a_e}\left(\frac{a}{\bar{\omega}_r}\right)^3 = \frac{2}{a^{3/2}H_o^{1/2}}\left(\frac{m_i}{e}\right)^{3/4} u_o^{3/2}\frac{Q}{(Q+m_ec^2/e)^{1/4}}$$

Hence H_s increases with u_o as $u_o^{3/2}$, and also increases with Q, as $Q^{3/4}$ when Q is large compared with m_ec^2/e $(=1700)$.

Taking the same values of a, H_o and u_o as in §4. 3, and inserting the minimum value of Q which ensures non-separation of the ions and electrons, we obtain corresponding minimum values of H_s, so that

$$(2) \qquad H_s > 3{\cdot}3\times10^{-6}\gamma \quad (\mathrm{H^+\ ions})$$
$$1{\cdot}7\times10^{-3}\gamma \quad (\mathrm{Ca^+\ ions})$$

Here the results are expressed in the unit 1γ $(=10^{-5}\Gamma)$.

These values of H_s are so small as to make it clear that in order to produce any appreciable magnetic disturbance, Q must far exceed the minimum values needed to ensure that the ions and electrons will keep together till their radial motion is brought to rest.

We therefore now consider what values of Q are required in order that H_s shall have the value 20γ (§1. 1); these, and the corresponding values of ν(§4. 1) and of $(\bar{\omega}_r/a)$, are as follows

$$(3) \qquad \left.\begin{array}{lll} H^+ \text{ ions:} & Q=2{\cdot}5\times10^{10}, & \nu=5\times10^{19} \\ \mathrm{Ca}^+ \text{ ions:} & 6\times10^{8} & 1{\cdot}2\times10^{18} \end{array}\right\} (\bar{\omega}_r/a)=14$$

If the particles approach to a minimum distance $5a$ (so that $(\bar{\omega}_r/a)=5$), H_s is increased $(14/5)^3$ (or 22) times, to 440γ; the corresponding values of Q are $(14/5)^4$ $(=60)$ times as great as before, namely $1{\cdot}5\times10^{12}$ ($\mathrm{H^+}$ ions) or 4×10^{10} ($\mathrm{Ca^+}$ ions).

4. 5. *The duration of the magnetic disturbance*—From §3. 5 (6) we see that, for $n>2$, H_s at any time is a constant multiple of the value of H_p at the points then occupied by the (united) current-sheet. For sheets capable of producing a maximum field-intensity of 20γ or more, Q is so large (§4. 4) that a_e is very nearly equal to 1, and therefore §3.5 (6) is equivalent (when $n=3$) to $H_s=2H_p=2H_o(a/\bar{\omega})^3$. Hence the distance of the current when H_s first becomes appreciable (say 5γ) is $23a$. If the radial velocity of the current-sheet remained at its initial value u_o, the time taken for the sheet to reach its minimum distance $\bar{\omega}_r$ from this point would be $(23a-\bar{\omega}_r)/u_o$. But owing to the retardation the actual time is longer, by the amount of the time-lag determined in §3.5 (14), namely $(\bar{\omega}_r/u_o)I_n(1)$. If $n=3$, $I_n(1)=0{\cdot}401$, and the time-lag, if $\bar{\omega}_r=14a$ and $u_o=10^8$ cm/sec, is 36 seconds. In this case the whole time of travel, from $23a$, is $[(\bar{\omega}/u_o)-(\bar{\omega}_r/u_o)(1-I_3)]$; this varies slightly with $\bar{\omega}_r$, and therefore with Q; if $\bar{\omega}_r=14a$, this travel-time is 93 seconds, and if $\bar{\omega}_r=5a$, it is 127 seconds.

Since the motion of the current-sheet, after the minimum distance has been reached, is exactly reversed (except for the small change due to a very slight loss of energy by radiation), the whole tim during which

any magnetic disturbance (produced as in this problem) is appreciable ($>5\gamma$, say) is double the above times; hence it is only about five minutes.

4. 6. *The electronic velocities*—So long as the two sets of charges remain together, so that they have the same radial velocity u, the electrons have the greater resultant velocity, because $m_i v_i = -m_e v_e$. The velocities v_i, v_e increase steadily up to the minimum distance $\bar{\omega}_r$, so that (when $n=3$) the maximum value of v_e is given, by §3. 5 (1, 9*a*), by

$$-v_e = \frac{ca^3 H_0}{a_e Q \bar{\omega}_r^2} = \frac{\bar{\omega}_r H_s}{2Q} c \tag{1}$$

where H_s is the intensity of the induced field when $\bar{\omega} = \bar{\omega}_r$.

If $H_s = 20\gamma$, and the positive charges are H^+ ions, by §4. 4 (3) we find that $-v_e/c = 3{\cdot}6 \times 10^{-5}$, or $-v_e = 10^6$ cm/sec; if the ions are Ca^+, $-v_e = 4 \times 10^7$. For more intense fields, and larger values of Q, $-v_e/c$ is approximately proportional to $Q^{-1/2}$, so that $-v_e$ (in the unseparated motion) always remains smaller than u_0, and the total speed $(u_e^2 + v_e^2)$ never much (if at all) exceeds u_0. The total ionic speed is always less than u_0, because the magnetic energy of the induced field is drawn almost entirely from the kinetic energy of the ions.

5. DISCUSSION OF THE PROBLEM IN RELATION TO ACTUAL MAGNETIC STORMS

5. 1. *Removal of the "hooking" difficulty*—The discussion (in §§3, 4) of the idealized problem of §2 may be regarded as removing the difficulty referred to in §8. 42 of our original paper, respecting the tendency of the electrons to "hook" themselves on to the lines of force, that is, to spiral round them. In a uniform magnetic field of intensity H, the radius r_e of the electronic spiral is $(cm_e v/eH)$; in the permanent field of our problem (where the intensity is the same as for the Earth's field in the equatorial plane), at a distance $\bar{\omega}$ from the axis, $r_e = 2 \times 10^{-7}\ v(\bar{\omega}/a)^3$, so that if $(\bar{\omega}/a) = 10$, and $v = u_0 = 10^8$, $r_e = 2 \times 10^4$ cm $= 200$ meters. A solitary electron set in motion with this velocity at this distance from the axis of our cylindrical permanent field (§2. 2) could never vary its distance from the axis by more than ± 200 meters—a range of $\bar{\omega}$ over which H is nearly uniform, though it may be shown that the actual slight variation of H will cause the electron to describe a trochoidal path round the axis, its distance remaining between the approximate limits $\bar{\omega} \pm r_e$. The Störmerian paths of solitary charges in the Earth's field exhibit in a more complicated way this limitation of the electronic motions, because they deal with electrons which approach from a great distance, where r_e is very large, so large that the variation of H within the distance r_e must be taken into account. Hence the path, from infinity (say), instead of being a simple spiral (or trochoid), is a simply or multiply looped path, from and back to infinity, but with a definite minimum distance $\bar{\omega}$ depending on the speed v, which remains constant. For an electron initially (at infinity) moving with a radial speed 10^8 cm/sec, this minimum distance is 4700*a*, so that no solitary electron projected from the Sun with such a speed could approach as near to the Earth as 10*a* or less (in the equatorial plane): the distance of closest approach for a solitary ion similarly projected is 110*a* (H^+ ion) or 17*a* (Ca^+ ion).

The analysis of our idealized problem, however, shows in detail how the electrostatic attraction between a neutral ionized set of particles is able to keep the electrons moving together with the ions, to distances far nearer the Earth (when Q is sufficiently great) than they could ever reach if alone; the paths described by the individual ions and electrons are moreover very simple: the inward radial velocity steadily decreases to zero, and is then reversed and increases again to its original value; the lateral or azimuthal velocities remain of the same sign throughout (for either type of charge), increasing steadily from zero to a maximum (at the time when the radial velocity is zero), and thereafter steadily decreasing to zero again.

Our doubts whether the electrostatic attraction between the ions and electrons could carry the latter far into the Earth's field now seem, indeed, surprising, because in §§2 to 4 of our original paper we had shown that a neutral ionized stream (whatever the form of its cross-section) could move transversely through a *uniform* magnetic field, without the motion being affected by the field in the *interior* of the stream (though in general the surface-layers would not be in equilibrium). In any case, however, it is helpful to know the accurate solution of a problem, such as the one here considered, in which a neutral ionized system of particles moves in a non-uniform field.

5. 2. *Some unreal features of our idealized problem*—The present problem differs from that of the first phase of an actual magnetic storm in several important respects, as follows:

(*a*) The magnetic fields involved are unidirectional everywhere; this limitation in itself is not serious, if we wish only to consider the motion of an actual solar ionized stream in the plane of the Earth's magnetic equator.

(*b*) The motions of the particles are plane motions; they, and the resulting electric currents, are the same in every plane z=constant. In an actual magnetic storm this will not be so; the currents near the surface of the hollow flow round two foci (cf. Fig. 3, a version of Fig. 3 of

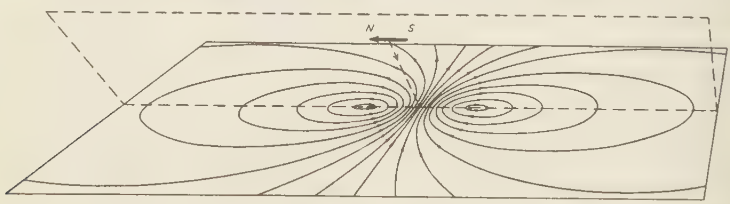


FIG. 3—CURRENT-LINES IN CONDUCTING PLANE SHEET WITHIN FIELD OF APPROACHING PARALLEL MAGNETIC DIPOLE, NS

[1], which showed the current-system of the RPC problem (§1.3) viewed from the Earth) so that at the points furthest from the equator the direction of current-flow is westward, instead of eastward as in the equatorial plane. Moreover the currents in our ideal problem circulate uniformly round the magnetic axis, whereas in the actual storm they lie mainly on the sunward side of the Earth. This is a consequence of the cylindrical symmetry (adopted for its mathematical convenience) of our idealized problem, which corresponds to a stream of particles ap-

proaching the Earth from a ring-sun surrounding the Earth at a great distance. Owing to this feature, the contribution made by each ion-electron pair to the magnetic disturbance in our problem will be several times as large as in an actual storm, where the field-contributions of different sections of the current-circuits are partly opposed. Consequently, to produce a given field-disturbance over a region of given size we require a greater amount of solar gas per unit volume of that disturbed region. Moreover this denser gas may be expected to approach nearer the Earth, for a given intensity of disturbance, than in our present problem. The same conclusion is indicated by the very different idealized problem (RPC) considered in §§7.1 to 7.6 of our former paper (the problem of the plane rigid conducting sheet approaching the Earth); we saw that for an external field-disturbance of 20γ at the Earth's center, the minimum distance of approach (corresponding to $\bar{\omega}_r$) must not exceed $7.5a$ (this corresponds to perfect conductivity of the sheet), instead of $14a$ as in §4.4.

(*c*) The disturbing field in our problem is uniform within the current-sheet, and zero outside it; in an actual storm the disturbance-field within the hollow will not be uniform, and the induced currents in the stream will probably partly shield the space "behind" the surface (that is, within the solar stream) from the Earth's field.

(*d*) The system of particles considered in our problem is confined to a single surface (so long as the two sets of particles do not separate) instead of extending throughout a volume. This feature is adopted for mathematical convenience, since it has the effect of reducing the solution of the problem to the determination of only two functions of the time (u and v_e or v_i). This advantage is dearly bought, however, because it removes from our problem a feature which we believe to be of essential importance in the first phase of actual magnetic storms. This feature is the continuous heaping up of matter in the surface-layer of the hollow, due to the advance of relatively unretarded matter, in the region "behind" the surface partly shielded from the permanent field. This question was discussed in §7.8 of [1], where it was shown that the approach of the surface from say $20a$ to $5a$ or $7a$ would occupy only a few minutes, but that thereafter the advance would be greatly slowed down (for streams of density 1 to 10 H^+ ion-pairs, or 0·025 to 0·25 Ca^+ ion-pairs per cc, in the almost undisturbed region of the stream at, say, $50a$). This heaping up would correspond, in our problem, to an increase of Q as the cylindrical shell of charges approaches the magnetic axis. It is evident from §3. 5 (7), if written in the simpler form

$$\left(\frac{u}{u_o}\right)^2 = 1 - \frac{K}{Q\bar{\omega}^{2n-2}}$$

that if Q increases as $\bar{\omega}$ diminishes, so that $Q\bar{\omega}^{2n-2}$ becomes a slowly varying function of $\bar{\omega}$, then the duration of the last stages of the motion, after $Q\bar{\omega}^{2n-2}$ has been reduced nearly to K, can be greatly increased.

It seems likely that the present problem, like that of §7.8 of [1], gives a valid indication of the observed rapidity of the initial increase (during the course of a few minutes) in the horizontal magnetic force during a magnetic storm [3]; the continuance of this increase over a period of a few hours, however, which is explained by §7.8 of [1], could

only be accounted for, in a cylindrical idealization of the storm-problem such as is here considered, by generalizing the system of particles so that it fills a thick cylindrical shell, or at least consists of a succession of distributions over several concentric cylindrical surfaces. We hope to examine these generalizations later.

(*e*) The motions of the particles in our problem are entirely "organized," without any random components (so that the gas has no "temperature," or kinetic energy of "peculiar" motion relative to the mean motion); also no consideration has been taken of the collisions or encounters between the two sets of charges, in the course of their opposed, azimuthal current-bearing motion. In the actual solar stream the ions and electrons probably have random motions, on emission, corresponding to a temperature of about 6000°, and these are likely to remain substantially unaltered during the passage of the gas towards the Earth. The organized *relative* motion of the two sets of charges, which produces the electric currents in the stream when this enters the Earth's field, must induce collisions that would set up random motions even if none were present already; the collisions partly "disorganize" the regular motions, and convert part of the energy of mean motion into energy of peculiar motion or heat energy. Thus the temperature of the gas must rise owing to this electrical-resistance effect. The conversion of part of the initial organized kinetic energy into heat instead of into energy of the magnetic disturbance-field will increase the estimate of the minimum value of Q needed to produce a 20γ-disturbance. We hope to return later to the consideration of these questions, of which a preliminary discussion was given in §§8, 9 of [1].

6. THE STREAM-DENSITY

6. 1. *Interpretation of Q in terms of the solar stream-density*—In §4. 4 it has been shown that in our idealized problem the value of ν $(=Q/e)$ needed to produce a 20γ-disturbance is 5×10^{19} (H^+ ions) or $1{\cdot}2\times10^{18}$ (Ca^+ ions), and that when the current-shell is brought to rest, at the maximum of the disturbance, $\bar{\omega}_r=14a$; the corresponding time-lag (t_r-t_r') was shown in §4.5 to be approximately one-half minute (36 seconds). We can interpret these results in terms of a volume-stream hypothesis, and from them get a rough estimate of N, the number of ion-electron pairs per cc in the stream just before it enters the Earth's field. To do this we suppose that ν represents the number of ion-pairs in a shell (of unit-length along Oz) of thickness $u_0\ (t_r-t_r')$; this is about $5a$. If we regard $25a$ as the distance at which the stream first begins to be appreciably affected by the permanent field, we may determine N for the shell of inner and outer radii $25a$, $30a$, with the mean radius $27.5a$. The volume is $\pi\ (30^2-25^2)a^2$ or $275\pi a^2$, so that $N=\nu/275\pi a^2$, which has the values 0.14 (H^+ ions) or 0·003 (Ca^+ ions). These extremely small values are much less than those found in §7. 8 of [1], probably for three main reasons: (*i*) in our problem the particles are converging from all sides, whereas in a solar stream their mean motions near the Earth (outside the Earth's field) are nearly parallel—the densities here calculated should probably be increased by about 10 on this account; (*ii*) as indicated in §5. 2 (*b*), the ion-pairs are more effective in producing the magnetic disturbance than in the case of a solar stream—a factor

of about 5 or 10 should allow for this smaller efficiency, giving, with the previous factor, an estimate of 7 to 14 (H^+ ions) or about 0·15 to 0·30 (Ca^+ ions). These are of the same order as those for curves *III* and *IV* of Figure 8 in [1].

6. 2. *The fate of streams of very low density*—It was shown in §§4.1-4.4 that any cylindrical surface-distribution of particles dense enough to produce an appreciable magnetic disturbance (by approaching to within a few Earth-radii from the axis) would remain united, and that a set of particles so rare that it could separate into two shells would do so before reaching a distance $890a$ (H^+ ions) or $280a$ (Ca^+ ions). There is little "geomagnetic" interest in considering such rare sets of particles, but it may be pointed out that the "separable" sets form a transition-stage between the magnetically effective type of solar stream, in which the ions and electrons are kept together by their mutual attraction, and the Störmerian problem of a solitary charge moving in the Earth's field. As the stream-density diminishes, the mutual influence of the ions and electrons will become less, and their motions will become more independent. The minimum value of ν for separation (§4.1), namely $1{\cdot}4\times 10^{11}(H^+)$ or $5{\cdot}6\times 10^{12}(Ca^+)$, is smaller in the ratio $4\times 10^8(H^+)$ or 2×10^5 (Ca^+) to 1 than that required for a 20γ-disturbance. Hence we may expect that in a solar stream the ions and electrons will not gain much freedom of relative radial motion unless the density N is of the order 10^{-8} (1 ion pair per 10^8 cc or per 100 cubic meters).

On this account we are not concerned to follow the motion of the two shells in our problem, after separation has occurred; but it may be remarked that since, as $Q \to 0$, the problem tends to the Störmerian one, the motion for small values of Q will tend to that of two shells (sparsely occupied) whose radial motions correspond to those of an electron alone, and an ion alone, projected towards the axis with the velocity u_0. As Q decreases, $\bar{\omega}_s$ increases proportionately to Q^{-n+1} (or Q^{-2} if $n=3$)—cf. §3.5 (5); as $Q \to 0$, the minimum ionic and electronic distances from the axis will be those corresponding to solitary particles, namely $4700a$ for the electrons, and $110a$ (H^+) or $17a$ (Ca^+) for the ions (§5.1). Thus as Q decreases below the separation-limit, the ion- and electron-shells will become greatly separated; also since their minimum radii will be attained at different times, u_i and u_e need not preserve the same sign. In the limit as $Q \to 0$, the ratios $m_i v_i$ and $-m_e v_e$ become equal, as they are up to the instant of separation, but §3. 6 (cf. (4)) suggests that for intermediate values of Q a reversal of v_e may occur.

7. AN ALTERNATIVE "CYLINDRICAL" ELECTROMAGNETIC PROBLEM

Our method of procedure in trying to check or establish our theory of magnetic storms has been to conceive and solve idealized problems illustrative of particular features of the complex series of phenomena which in our view make up the storm. In order to make certain of the ability of the ions (in a sufficiently dense stream) to draw the electrons onwards, without spiralling, into the more intense regions of a magnetic field, we first considered an idealized problem (CS′) different from the one (CS) discussed in §§2 to 6 of the present paper. The system of particles and their initial motion are the same as that of §§2. 3, 4, and they move in a permanent magnetic field possessing cylindrical sym-

metry, but the type of this symmetry differs from that of §2. 2. Instead of being unidirectional, the lines of magnetic force are circles around the z-axis (their equations being $\bar{\omega}$=constant, z=constant); hence $H_{\bar{\omega}}=H_z=0$ and $H(=H_\phi)$ is supposed to be a function of $\bar{\omega}$ only; a field having the same law of variation as in §2. 2 (for $n=3$), was considered, namely $H=H_o\,(a/\bar{\omega})^3$, for $\bar{\omega}>a$; this could be produced by a line-current of magnitude $\frac{1}{2}aH_o$ along the z-axis, and a volume-distribution of current-density outside $\bar{\omega}=a$, given by $c_{\bar{\omega}}=0$, $c_\phi=0$, and $c_z=-a^3H_o/2\pi\bar{\omega}^4$; the vector-potential **A** is given by $A_{\bar{\omega}}=0$, $A_\phi=0$, $A(=A_z)=a^3H_o/2\bar{\omega}^2$.

In this CS'-problem the motions of the individual ions and electrons are confined to planes through the z-axis, the ϕ-component of **v**, namely v, being zero; the transverse velocity-component is now w. The ionic and electronic shell (or shells, if they separate) becomes a cylindrical current-sheet with current-flow parallel to the z-axis. The magnetic field of such a current-sheet, if stationary and of constant strength C, is zero within the sheet and $2C/\bar{\omega}$ outside it; the field-energy per unit-length is infinite. Since the energy of the field of the current in the sheet is drawn from the kinetic energy of the particles, it is not possible to ignore the propagation of the field-changes (as was done in the CS-problem, §2.7); in order to preserve the energy-relations the finite velocity of propagation must be considered, and this unfortunately renders the CS'-problem much less tractable than the CS-case considered in §§2 to 6. Nevertheless we obtained an approximate solution which is correct as regards orders of magnitude. The investigation, which is long, will not be given, as the main points involved are more simply illustrated by the CS-problem of §§2 to 6, which was devised later.

The CS'-results, as regards the motions of the charges, their separation, and the minimum distance from the axis, depend on Q in much the same way as in §§2 to 6, and show that the electrostatic field can hold the ions and electrons together if Q is large enough.

A curious difference between this and the CS-problem of §§2 to 6 is that the latter illustrates the magnetic disturbance within the cylindrical shell of particles, but (owing to the special character of the field of a solenoidal current-sheet) does not illustrate the shielding of the outer space from the permanent field; in the CS'-problem, the current-sheet has no magnetic field within the shell, so that though it illustrates the partial shielding of the outer space from the permanent field, it does not illustrate the magnetic disturbance.

References

[1] S. Chapman and V. C. A. Ferraro, Terr. Mag., **36**, 77-97, 171, 186 (1931); **37**, 147-156, 421-429 (1932); **38**, 79-96 (1933).
[2] V. C. A. Ferraro, Observatory, **56**, 253 (1933).
[3] W. van Bemmelen, Proc. Amsterdam Acad., 1908, pp. 773-782; W. J. Peters and J. W. Green, Terr. Mag., **36**, 99-104 (1931).

Imperial College of Science and Technology (S.C.),
South Kensington, London, England

King's College (V.C.A.F.),
Strand, London, England

GEOMAGNETIC TIDES IN HORIZONTAL INTENSITY AT HUANCAYO

By J. Bartels and H. F. Johnston

Part I

Abstract—Following an introductory survey of the main features of the solar and lunar daily variations, S and L, in horizontal intensity, H, in January at Huancayo, days with conspicuous lunar influences, geomagnetic tides, are discussed. A separation of S and L on such "big-L-days" is attempted. Daily ranges A in H are then introduced for the study of the intensity of S and, thereby, of the solar wave-radiation W. Up to international character-figures $C=1.1$, A is found independent of changes in the solar corpuscular radiation P.

Various methods for studying L are compared. Lunar semimonthly waves in the ranges A are computed and discussed in their change with season and sunspot-cycle. In the months November to March, when L is larger than in the rest of the year, L and S increase, in their effects on A, proportionally to each other from sunspot-minimum to sunspot-maximum, but around June, when L is small, it does not participate in the change of S with the sunspot-cycle. The day-to-day variability of S and L is studied in some detail; S and L fluctuate rather independently of each other, and the relative fluctuations of L seem to be greater than those of S. The elimination of the lunar effect A_L is described; $(A-A_L)=A_S$ is proposed as a measure for W.

A more extensive summary, including some results to be described in Part II, has been published elsewhere [see 4 of "References" at end of paper].

§ 1. *Introduction*

The time-variations in the horizontal intensity H recorded, since March 1922, at the Huancayo (Peru) Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, are known to show singularly large amplitudes A in the solar daily variations S. In connection with a plan [21] to use S for a day-by-day measure of the intensity W of solar wave-radiation, it became necessary to eliminate the effects of the lunar daily variations L. In contrast to the experience at other observatories where L is small and can only be extracted from many hourly values, L in H at Huancayo was found to be of exceptional magnitude, not only in absolute units, but even relative to S, thus offering unique material for the study of L, for which the name *geomagnetic tides* seems fitting.

For conciseness, abbreviations and symbols have been used as listed in § 2. The main results have been described elsewhere [4] in less technical language; the background for this study is given in two recent books [1, 2]. General statistical methods for the determination of S and L have recently been authoritatively described by S. Chapman and J. C. P. Miller [3]; the methods used in the present paper differ in so far as the greater magnitude of L in H at Huancayo permits one to go beyond the harmonic analysis of daily variations, and to determine the influence of L in the semimonthly waves for every hour of the solar day. As will be described in Part II, the latter method (developed from what is described as "van der Stok's" method in [1], as recently applied by M. Bossolasco [18], J. Egedal [19], and W. J. Rooney [20]) provides a direct approach to the study of the change of L with day and night.

Of course, all computations had to be planned on the basis of previous work, namely, on the observational and statistical side, on known data for S and L, for the tides in the atmosphere, and for the physics of the ionosphere, and, on the theoretical side, on the dynamo-theory of L and the theory of tidal gravitational forces and tidal atmospheric motions. But the quantitative results will be described as well-defined abstracts of the observations, independent, as far as possible, of theoretical assumptions or working hypotheses. The series March 1922 to October 1939 provided more than 150,000 hourly means of H.

§ 2. *Abbreviations, symbols, groupings*

(1) t = mean local solar time, increasing in a mean solar day, between successive midnights, from 0 to 2π, or 0° to 360°, or 0^h to 24^h. H at Huancayo is tabulated in the form of hourly means for 0^h-1^h, etc., standard 75° west meridian time; for Huancayo Observatory, which lies in 75°.3 west, mean local time t = (standard time $-$ 0°.3) = (standard time $-$ 0.02 hour).

(2) τ = mean local lunar time, increasing in a mean lunar day, between successive lower transits of the mean Moon, from 0 to 2π, or 0° to 360°, or 0^s to 24^s, where the affix s (from the Greek *selene*) marks lunar hours of 15° in τ, after Ad. Schmidt [17]. Within a mean solar hour, t increases by 15°, and τ by (15° $-$ 0°.50795). One lunar hour equals 1.03505 solar hours.

(3) ν = age of the mean Moon at Greenwich mean noon, or 7^h Huancayo standard time, or $6^h.98$ Huancayo mean local time. ν is the angle $(t-\tau)$ between the meridian planes through the mean Sun and the mean Moon, increasing from 0° to 360°, or 0 to 24 hours (of 15° each) between successive mean new Moons, in a synodic month of 29.5306 solar days = 28.5306 lunar days. In this paper, the phase of the mean Moon for a whole day will always be characterized by its age ν at Greenwich noon; the symbol ν will be reserved for this value, while the *variable* age of the mean Moon (increasing by 12°.1907 or 0.8127 hour per solar day) will be denoted by $(t-\tau)$. Therefore:

(4) $\tau = t - \text{age} = t - \nu - (\text{age} - \nu)$, or, if τ, t, ν are expressed in degrees

(4*a*) $\tau = t - \nu - 0.0339\ (t - 104°.7)$, or, on division by 15°, τ, t, and ν are expressed in hours

(4*b*) $\tau = t - \nu - 0.0339\ (t - 6^h.98)$

At Huancayo mean noon, the age $(t-\tau)$ is $(\nu + 2°.55) = (\nu + 0.17)$ hours. The times of the lower or upper transits are obtained from (4) by putting $\tau = 0°$ or 180°.

ν is computed from the parameter $\mu = (24 - \nu)$ hours, introduced by Ad. Schmidt, and tabulated in the "Mondalmanach" [5] and the "Mondtafeln" [6]. ν increases by 4.06 hours in five solar days; therefore, pairs of days occur with the same value of ν to the nearest hour.

(5) $(s-p)$ = angular distance of the mean Moon from its perigee: From perigee to perigee, the anomalistic month, of 27.5546 days, is divided into four quarters (after S. Chapman), centered at the epochs $(s-p) = 0°$, 90°, 180°, 270°, referred to as PERigee, RECeding, APOgee, and NEAring. In practice, the quarters PER and APO comprise the seven days centered at the dates of

mean perigee and apogee as tabulated in the "Mondtafeln" [6], and the quarters REC and NEA are the six or seven days between, on the average, 6.777 days.

(6) M_2, N_2, L_2, $2N$ = partial lunar tides, see Part II.

(7) Seasonal groups: December-solstice = November to February; equinoxes = March, April, September, October; June-solstice = May to August. In order to reduce accidental errors, smoothed monthly groups have occasionally been formed in the sense that "January" means [(December + 2 × January + February)/4], etc.

(8) H = horizontal force at Huancayo, expressed in the unit $\gamma = 10^{-5}$ cgs; occasionally the unit $0.1\gamma = 10^{-6}$ cgs = microgauss was found more convenient.

(9) S and L, solar and lunar daily variations: On each day, $\mathsf{S} = \mathsf{S}_q + \mathsf{S}_D$, a superposition of a quiet daily variation S_q and a disturbance daily variation S_D. On undisturbed days—see (10)—S_D in H is negligible, so that $\mathsf{S} \equiv \mathsf{S}_q$. Average variations for a number of days, as distinguished from those on single days, will be denoted by S^* and L^* in § 6; $\mathsf{L}_\perp{}^*$ is defined in § 7. Days with conspicuous lunar influence will be called "big-L-days" (§ 4, § 5).

(10) C = International magnetic character-figure, between 0.0 and 2.0, used as a measure for the intensity of the solar corpuscular radiation P (particles) reaching the Earth: Undisturbed days, defined here by $C < 1.2$, are always considered without further distinction, except in § 13, where the days in each month are classified according to C as follows: The quietest five days (the "international quiet days") form the group q_0; the next five, q_1; the third five, q_2; the remaining days with $C < 1.2$ (if any are left) form group q_3; the days with $C \geqq 1.2$ form group d.

(11) R = relative sunspot-numbers for the whole Sun's disk as given by the Zürich Sternwarte, used as a preliminary measure of the intensity of the solar ionizing wave-radiation W. Four groups of months according to R were formed, called Min_1, Min_2, Max_3, Max_4, of necessarily unequal size, as indicated in Table 1; they are sometimes combined into two groups, $\text{Min} = \text{Min}_1 + \text{Min}_2$, and $\text{Max} = \text{Max}_3 + \text{Max}_4$. Smoothed groups are "$\text{Min}_1$" = $(2\ \text{Min}_1 + \text{Min}_2)/3$, "$\text{Min}_2$" = $(\text{Min}_1 + \text{Min}_2 + \text{Max}_3)/3$, "$\text{Max}_3$" = $(\text{Min}_2 + \text{Max}_3 + \text{Max}_4)/3$, "$\text{Max}_4$" = $(\text{Max}_3 + 2\ \text{Max}_4)/3$.

(12) Several kinds of daily ranges of H: The range A (meaning "amplitude," in order to reserve R for sunspot-numbers) used most here is the excess of the five-hour mean $(9 \text{ to } 14)^{\text{h}}$ over the night-level

TABLE 1-A—*Sunspot-groups* (Min_1, Min_2, Max_3, Max_4)

Months	Year, 1900+																	
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	Months in sunspot-group																	
January, February	.	1	1	2	3	4	3	3	4	2	1	1	1	2	3	4	4	4
March, April	2	1	1	2	3	4	4	3	3	2	1	1	1	2	3	4	4	4
May to August	1	1	2	3	3	3	4	4	2	2	1	1	1	2	3	4	4	4
September, October	1	1	2	3	3	3	4	2	2	2	1	1	1	3	4	4	4	4
November, December	1	1	2	3	4	3	3	4	2	1	1	1	2	3	4	4	4	.

TABLE 1-*B*—*Average Zürich relative sunspot-numbers, R*

Group	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Dec.-solst	Equinox	June solst.
Min_1	6	10	6	8	10	10	7	4	6	7	9	10	9	7	8
Min_2	13	27	32	22	28	28	25	22	28	31	22	19	20	28	26
Max_3	72	70	56	51	60	63	49	60	58	64	60	66	67	57	58
Max_4	91	93	78	99	99	98	115	102	94	92	90	98	93	91	104
Min	9	17	18	14	18	18	15	12	16	18	14	13	13	16	16
Max	83	83	68	78	82	83	86	83	78	80	77	83	82	76	84
All	48	52	43	46	50	50	51	48	47	49	47	51	49.5	46.1	49.7

$(0$ to $5)^h$; A_L is the lunar effect on A, and $A-A_L=A_S$. The deviations of A and A_S from their averages for the calendar month are $\triangle A$ and $\triangle A_S$. Ranges of instantaneous values, published as R_H in the "Caractère magnétique numérique des jours" for the years 1930 to 1939, will be compared with A in § 13.

(13) Lunar semimonthly waves in the ranges A: $a_A \cos 2\nu + b_A \sin 2\nu = c_A \sin(2\nu + \alpha_A)$, see § 14.

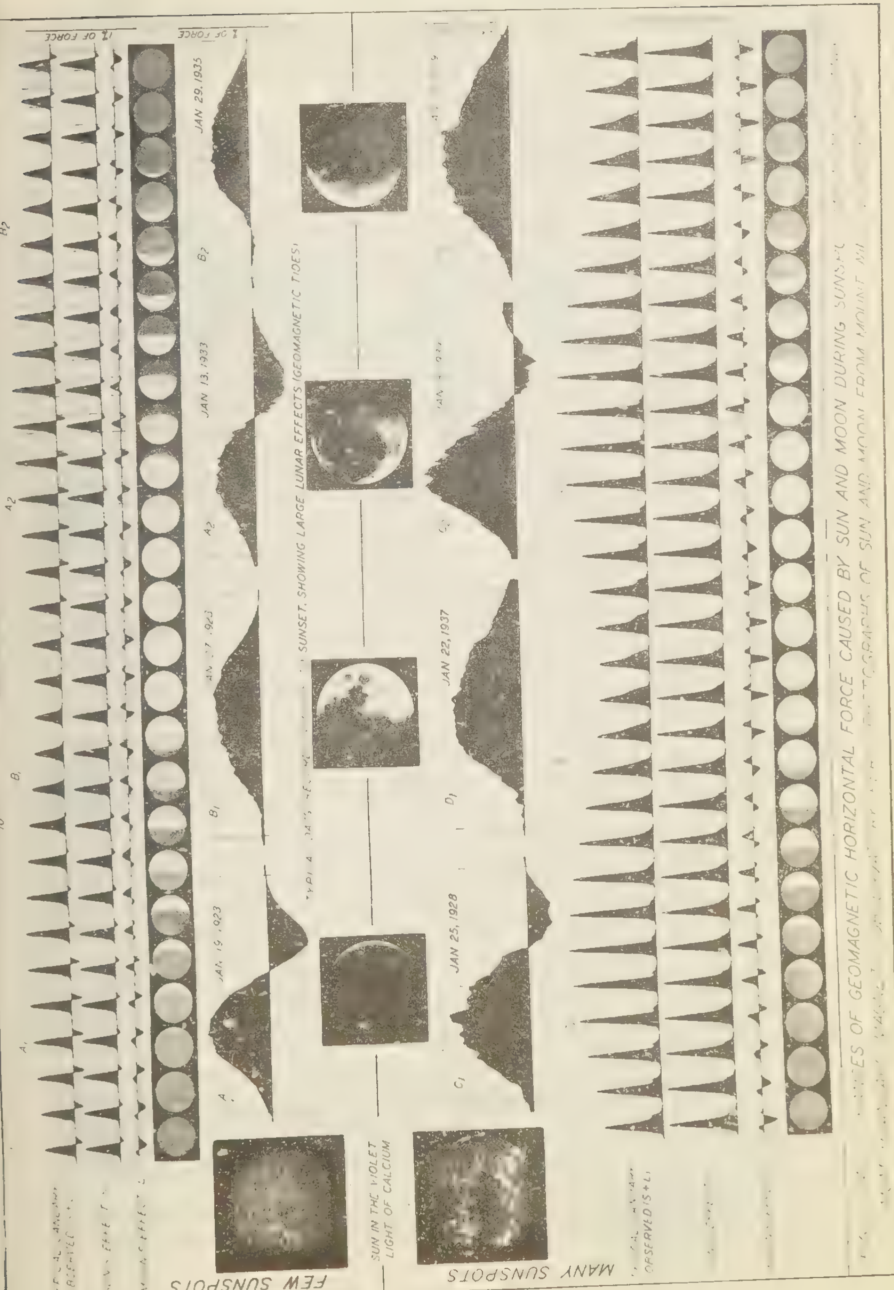
(14) Probable error-circle radii ρ of clouds of points in harmonic dial: See § 15.

§ 3. *A preliminary description of the main features of* L

The details of the calculations will be more easily explained by beginning with an advance summary of the main features of S and L in *H* at Huancayo; these are combined in Figure 1 for the month of January, when L is great. The upper half of the diagram refers to sunspot-minimum, the lower half to sunspot-maximum [Min and Max, see § 2(11); average sunspot-numbers for January $R=9$ and $R=83$]; the solar activity is pictured, at the left, by two spectroheliograms taken in calcium light at Mount Wilson Observatory. The phases of the Moon are pictured by schematic disks for $\nu=0, 1, 2, \ldots 24$ hours.

The two frieze-like diagrams at the upper and lower borders of Figure 1 are derived from all observations on undisturbed days. They show the systematic superposition of S (second row) and L (third row) to form the observed daily variation (S+L) (first row). The ordinate scale is indicated by the vertical lines at the right which give 296γ—one per cent of the average *H* at Huancayo. Only the average variations are shown in the friezes, as if S and L were completely determined by the season (here, the month of January), the sunspot-number, and, in the case of L, by the age ν of the Moon; the friezes are therefore schematic in so far as they show neither the additional irregular fluctuations from day to day (4) nor the change of L with the distance of the Moon from the Earth (Part II).

S, L, and (S+L) are pictured as departures from the night-level because the main swing of the curves is confined to the daytime (Part II); day and night are roughly separated by vertical lines drawn at 6^h and 18^h. L can be described as a lunar semidiurnal wave with maxima about seven hours after the Moon's transits; this wave appears only in daytime


DAYS OF MONTH
1% OF FORCE
FEW SUNSPOTS
SUN IN THE VIOLET LIGHT OF CALCIUM
MANY SUNSPOTS
JAN 19, 1923
JAN 13, 1933
JAN 29, 1935
JAN 25, 1928
JAN 22, 1937
SUNSET, SHOWING LARGE LUNAR EFFECTS (GEOMAGNETIC TIDES)
OBSERVED (S+L)
ES OF GEOMAGNETIC HORIZONTAL FORCE CAUSED BY SUN AND MOON DURING SUNSPOT

and is suppressed at night. The tidal cause of L is evident in the similarity of the curves for the two halves of the synodic month, since upper and lower transits of the Moon are equivalent in the semidiurnal tidal forces.

At sunspot-maximum, both S and L have greater amplitudes than at sunspot-minimum; S changes also its form, in that the small downward swing in the afternoon is flattened out at sunspot-maximum.

§ 4. *Cases of exceptionally large lunar influences*

Actually the daily curves vary not only systematically as pictured in the two friezes of Figure 1, but also in a less regular manner from day to day. This is a well-known property of S, although some of the "variability" formerly ascribed to S is actually the result of the superposed L-variation which had been underestimated. The large magnitude of L in Huancayo H affords for the first time the opportunity to detect striking changes in the amplitude of L from day to day. The average daily curves obtained from many observations represent S as a function of season and sunspot-number R, and L as a function of season, sunspot-number R, and age ν of the Moon; these average curves may be called S* and L* and can be computed for each day from R and ν, once these functions have been determined (see § 8). Compared with (S*+L*), the actual records show that L is smaller than L* on certain days and unmistakably magnified, sometimes twofold or higher, on other days.

While the computation of the average S* and L* (to be described in Part II) is comparatively straightforward, the evidence for the variability of S and L is perhaps less compelling and more difficult to substantiate. But the inspection of a large number of daily magnetograms leaves no doubt that the abnormal shapes of certain daily curves are caused by an accentuation of L and not simply by a change of S. Such cases are most conspicuous at those phases of the Moon when the L-curve has a conspicuous swing between 14^h and 18^h, when, namely, the main forenoon swing of S has subsided so that L may dominate the observed curve (S+L). This makes the days with $\nu = 2$, 8, 14, or 20 hours—marked by the letters A_1, B_1, A_2, B_2 on the minimum frieze, and C_1, D_1, C_2, D_2 on the maximum frieze—most suitable in the search for "big-L-days": The downward swing of L in the afternoon on the days marked A or C appears conspicuously in (S+L), while the corresponding upward swing of L in the afternoon a quarter-month later on the days marked B and D protracts the forenoon maximum of (S+L) well into the afternoon.

The center of Figure 1 shows actual daytime records of H between 6^h and 18^h for "big-L-days," marked by the same letters; actual photographs of the Moon (taken at Mount Wilson Observatory and kindly provided by Dr. F. E. Wright) indicate the age ν of the Moon. These selected records show the lunar influence more pronounced than the friezes. They demonstrate well the tidal origin of L: Curve A_1 is similar to A_2, B_1 to B_2, C_1 to C_2, D_1 to D_2, thus pairing those ages of the Moon in which the times of upper and lower transits (or light and shadow on the Moon's disk) are interchanged, while contrasting those ages differing by six hours for which L is inverted.

For the selection of these days the magnetograms from 1923 to 1939 were available; magnetic disturbance limits the choice so that not more

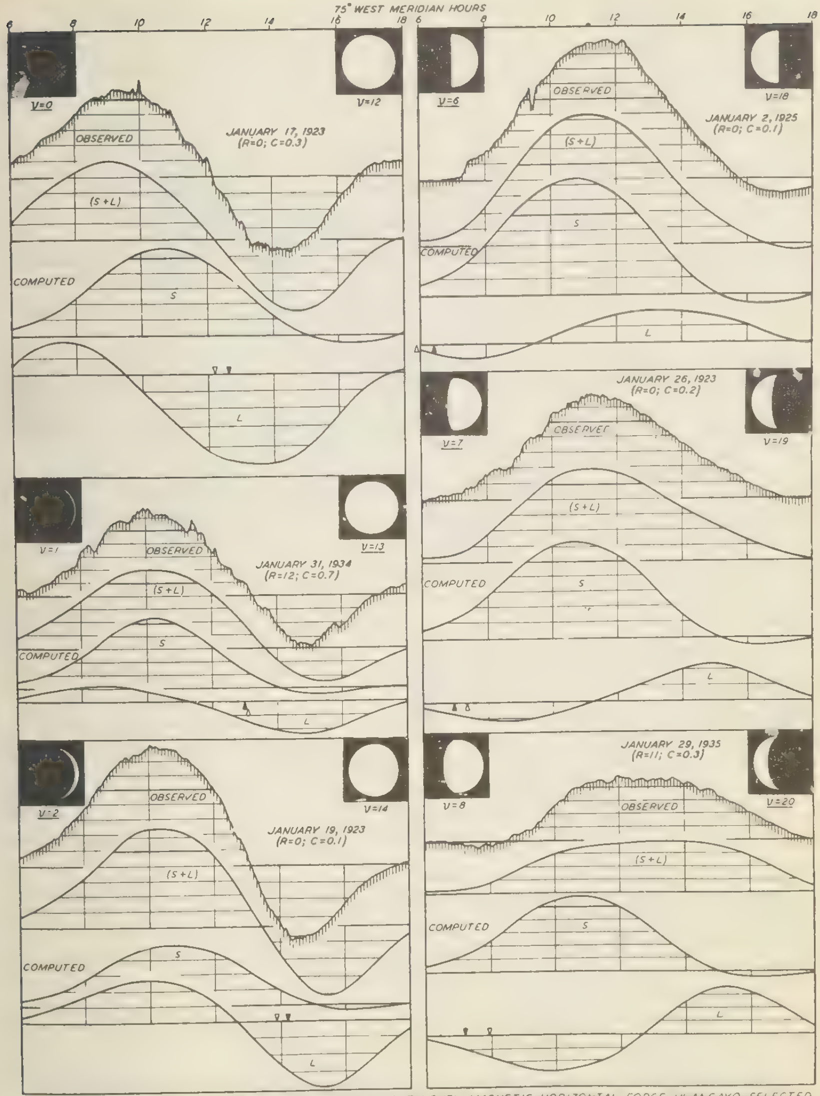


FIG 2—FOR SUNSPOT-MINIMUM, DEPARTURES FROM NIGHT-LEVEL, MAGNETIC HORIZONTAL FORCE, HUANCAYO, SELECTED QUIET DAYS WITH CONSPICUOUS GEOMAGNETIC TIDES IN JANUARY SHOWING INVERSION LEFT TO RIGHT OF TIDAL EFFECT WITH AGE (ν) OF MEAN MOON IN HOURS—UNDERSCORED FOR DATE GIVEN WHICH ALSO TYPIFIES ($\nu \pm 12$); R=SUNSPOT-NUMBER, C=MAGNETIC CHARACTER-FIGURE; UPPER AND LOWER TRANSITS: ▽▼ FOR MEAN MOON, ▼▲ FOR APPARENT MOON; SCALE 20γ PER DIVISION

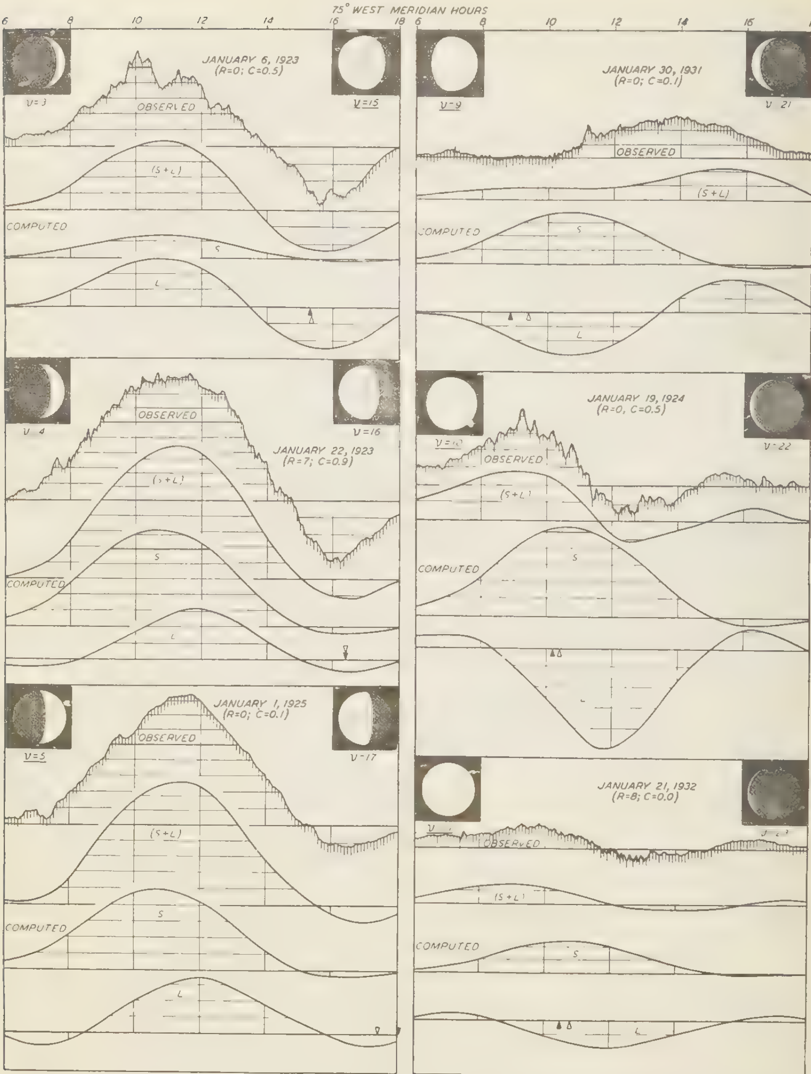


FIG. 3—FOR SUNSPOT-MINIMUM; DEPARTURES FROM NIGHT-LEVEL, MAGNETIC HORIZONTAL FORCE, HUANCAYO, SELECTED QUIET DAYS WITH CONSPICUOUS GEOMAGNETIC TIDES IN JANUARY SHOWING INVERSION LEFT TO RIGHT OF TIDAL EFFECT WITH AGE (ν) OF MEAN MOON IN HOURS—UNDERSCORED FOR DATE GIVEN WHICH ALSO TYPIFIES ($\nu \pm 12$); R=SUNSPOT-NUMBER, C=MAGNETIC CHARACTER-FIGURE; UPPER AND LOWER TRANSITS FOR MEAN MOON, FOR APPARENT MOON; SCALE 20γ PER DIVISION

than about eight days in January were available from which to choose each of the eight records reproduced in the center of Figure 1. These types of curves are therefore not very rare; this can also be seen from the fact that two of the contrasting pairs of magnetograms shown are for January days only a quarter-month apart, namely, A_1 and B_1, and C_2 and D_2.

TABLE 2—*Eight selected "big-L-days" in Figure 1*

[Age ν of mean Moon, distance $(s\text{-}p)$ from mean perigee—both in hours at Greenwich noon—sunspot-number R, international magnetic character-figure C, magnification-factors σ and λ in $(\sigma S^* + \lambda L^*)$]

Day	Date	ν	$(s\text{-}p)$	R	C	σ	λ
			Sunspot-minimum				
A_1	Jan. 19, 1923	1.6	8.7	0	0.1	0.8	4.1
B_1	Jan. 27, 1923	8.2	15.7	0	0.0	0.5	3.5
A_2	Jan. 13, 1933	13.6	17.0	42	0.1	0.6	3.4
B_2	Jan. 29, 1935	19.9	18.7	11	0.3	1.2	4.0
			Sunspot-maximum				
C_1	Jan. 25, 1928	2.5	20.4	116	0.6	0.5	2.9
D_1	Jan. 22, 1937	8.3	1.6	163	0.3	1.4	2.4
C_2	Jan. 8, 1939	14.2	1.2	78	0.8	0.9	3.1
D_2	Jan. 15, 1939	19.9	7.3	86	0.3	1.3	2.4

Table 2 gives details for the eight selected records, including the magnification-factors σ and λ which approximate the observed curve by the combination $(\sigma S^* + \lambda L^*)$ of the average variations S^* and L^* for sunspot-minimum and sunspot-maximum (§ 6). These parameters σ and λ should be accepted as rather hypothetical estimates for reasons given in § 6. Table 3 gives the average variations.

§ 5. *The model-sets of "big-L-days"*

All 527 January magnetograms, 1923-39, were systematically searched for "big-L-days," and two model-sets were selected for sunspot-minimum (Figs. 2 and 3) and sunspot-maximum (Figs. 4 and 5) for prospective use as guiding examples in measuring three-hour-range indices K. Each set consists of 12 daytime curves, namely, one curve for each age ν of the Moon to the nearest hour; in contrast to Figure 1, no distinction was made between the ages ν or $(\nu \pm 12)$ hours, because the main tidal effects should be the same for ν or $(\nu \pm 12)$, if distance-effects are neglected.

Table 4 gives data for the days of the model-sets. The average sunspot-numbers for the days in the two sets are $R=3$ and $R=84$. Only quiet days were selected (average $C=0.34$); thus the number of days (with $C<1.0$, say) from which to select each curve was not higher than 16. Since, for most ages ν, several magnetograms were found just as typical as the one finally selected for the model-set, it can be said that out of

TABLE 3—*Average solar and lunar daily variations* S* *and* L* *in horizontal intensity, Huancayo, January, 1923-1939, for sunspot-minimum and sunspot-maximum, in departures of hourly means from night-level*

[L* is given for a quarter-month only, for ages $\nu=0$ to 5 hours; $L^*(\nu+12)=L^*(\nu)$; $L^*(\nu+6)=L^*(\nu+18)=-L^*(\nu)$; d=average departure, without regard to sign, for daytime 06^h to 18^h; $d_\perp$ is explained in § 7]

Mean solar hour	Sunspot-minimum, $R=9$: S*	L* for $\nu=$ 0	1	2	3	4	5
h h	0.1γ	0.1γ	0.1γ	0.1γ	0.1γ	0.1γ	0.1γ
00–01	+ 2	.....	.....	.....	.....	.....	.....
01–02	0	.....	.....	.....	.....	.....	.....
02–03	+ 3	.....	.....	.....	.....	.....	.....
03–04	+ 7	.....	.....	.....	.....	.....	.....
04–05	+ 17	.....	.....	.....	.....	.....	.....
05–06	+ 50	− 1	+ 3	+ 7	+ 8	+ 7	+ 4
06–07	+132	+ 41	+ 40	+ 28	+ 9	− 13	− 31
07–08	+283	+ 63	+ 72	+ 62	+ 35	− 1	− 37
08–09	+569	+ 49	+ 86	+100	+ 87	+ 51	+ 2
09–10	+848	0	+ 76	+132	+152	+132	+ 76
10–11	+978	− 66	+ 34	+124	+181	+190	+136
11–12	+916	−107	− 7	+ 95	+172	+202	+179
12–13	+699	−143	− 72	+ 18	+104	+161	+176
13–14	+370	−147	−133	− 83	− 10	+ 65	+123
14–15	+ 98	−135	−170	−159	−106	− 24	+ 64
15–16	− 45	−104	−165	−181	−149	− 77	+ 16
16–17	− 70	− 45	−105	−136	−131	− 91	− 27
17–18	− 38	− 1	− 37	− 63	− 72	− 62	− 35
18–19	− 3	+ 5	+ 1	− 4	− 7	− 9	− 8
19–20	− 5	.....	.....	.....	.....	.....	.....
20–21	− 6	.....	.....	.....	.....	.....	.....
21–22	− 3	.....	.....	.....	.....	.....	.....
22–23	− 3	.....	.....	.....	.....	.....	.....
23–24	+ 1	.....	.....	.....	.....	.....	.....
d	420	75	83	98	101	89	75
$d_\perp$	.....	67	83	82	62	36	40

Mean solar hour	Sunspot-maximum, $R=83$: S*	L* for $\nu=$ 0	1	2	3	4	5
h h	0.1γ	0.1γ	0.1γ	0.1γ	0.1γ	0.1γ	0.1γ
00–01	− 4	.....	.....	.....	.....	.....	.....
01–02	+ 1	.....	.....	.....	.....	.....	.....
02–03	+ 9	.....	.....	.....	.....	.....	.....
03–04	+ 16	.....	.....	.....	.....	.....	.....
04–05	+ 28	+ 13	+ 10	+ 5	− 2	− 8	− 1[illegible]
05–06	+ 72	+ 35	+ 34	+ 25	+ 9	− 10	− 2[illegible]
06–07	+ 185	+112	+113	+ 84	+ 32	− 28	− 8[illegible]
07–08	+ 412	+163	+202	+188	+123	+ 25	− 8[illegible]
08–09	+ 834	+136	+232	+265	+227	+128	− [illegible]
09–10	+1244	0	+159	+275	+318	+275	+15[illegible]
10–11	+1481	−150	+ 39	+217	+338	+367	+29[illegible]
11–12	+1432	−276	− 80	+137	+317	+413	+39[illegible]
12–13	+1163	−346	−196	+ 7	+208	+354	+40[illegible]
13–14	+ 769	−320	−260	−131	+ 34	+189	+29[illegible]
14–15	+ 452	−244	−285	−249	−147	− 5	+13[illegible]
15–16	+ 237	−124	−218	−255	−223	−131	− [illegible]
16–17	+ 162	− 21	−115	−179	−195	−158	− 8[illegible]
17–18	+ 129	+ 31	− 24	− 72	−101	−103	− 7[illegible]
18–19	+ 70	+ 16	+ 3	− 11	− 23	− 28	− 2[illegible]
19–20	+ 34	+ 12	+ 15	+ 14	+ 9	+ 5	− [illegible]
20–21	+ 16	+ 1	+ 7	+ 11	+ 11	+ 10	+ [illegible]
21–22	+ 10	.....	.....	.....	.....	.....	.....
22–23	+ 4	.....	.....	.....	.....	.....	.....
23–24	− 2	.....	.....	.....	.....	.....	.....
d	708	160	160	172	189	181	168
$d_\perp$	.....	128	159	155	121	83	91

every ten days in January at least one shows L as prominently as the magnetograms in Figures 2 to 5.

The "observed" curves are tracings of the magnetograms for daytime, 6^h to 18^h. A straight line has been drawn connecting the consecutive night-levels—slightly sloping because of non-cyclic variation—and the scale is indicated by parallel lines drawn for intervals of 20γ; since the scale-value of the H-variometer, for instrumental reasons [7], changes across the magnetogram, these horizontal lines are more narrowly spaced near the top of the curves, as is plainly visible in the curve for $\nu=2$ in Figure 2. The instrumental effect of temperature-changes, less than 1γ, is negligible.

Each "observed" curve has been approximated by a "computed" curve, marked (S+L), which is a superposition of two curves marked

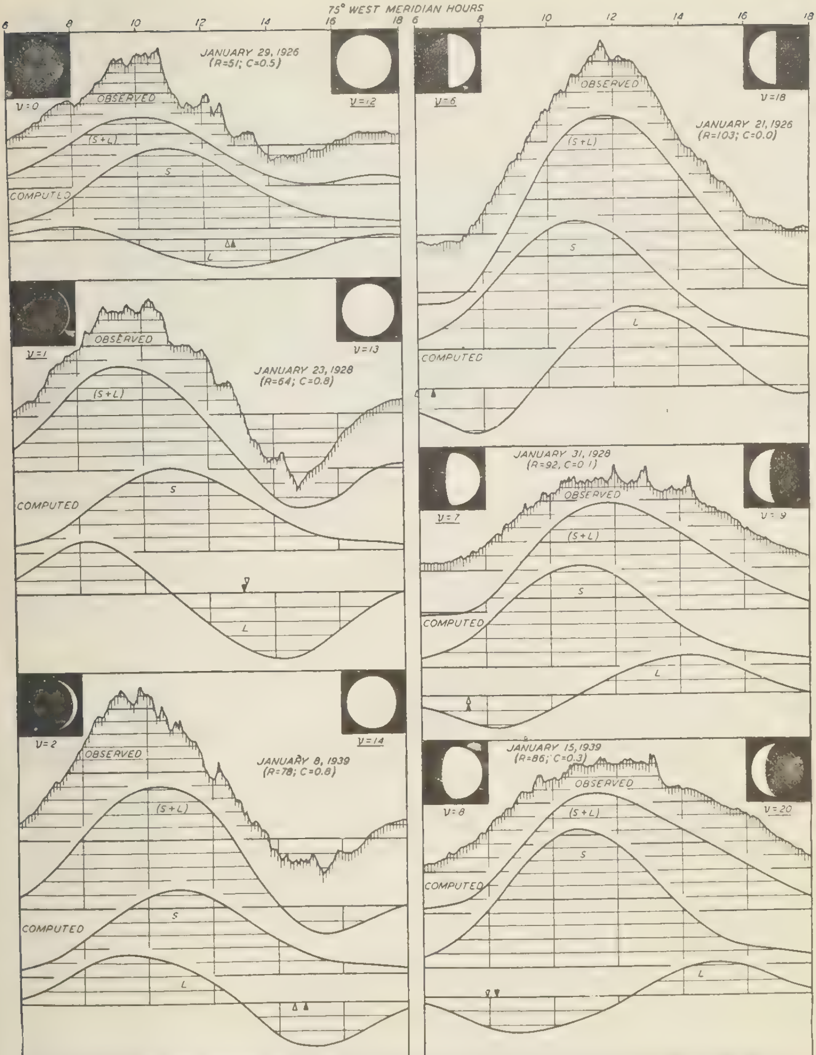


FIG. 4—FOR SUNSPOT-MAXIMUM; DEPARTURES FROM NIGHT-LEVEL, MAGNETIC HORIZONTAL FORCE, HUANCAYO, SELECTED QUIET DAYS WITH CONSPICUOUS GEOMAGNETIC TIDES IN JANUARY SHOWING INVERSION LEFT TO RIGHT OF TIDAL EFFECT WITH AGE (ν) OF MEAN MOON IN HOURS—UNDERSCORED FOR DATE GIVEN WHICH ALSO TYPIFIES (ν±12); R=SUNSPOT-NUMBER, C=MAGNETIC CHARACTER-FIGURE; UPPER AND LOWER TRANSITS ▽△ FOR MEAN MOON, ▼▲ FOR APPARENT MOON; SCALE 20γ PER DIVISION

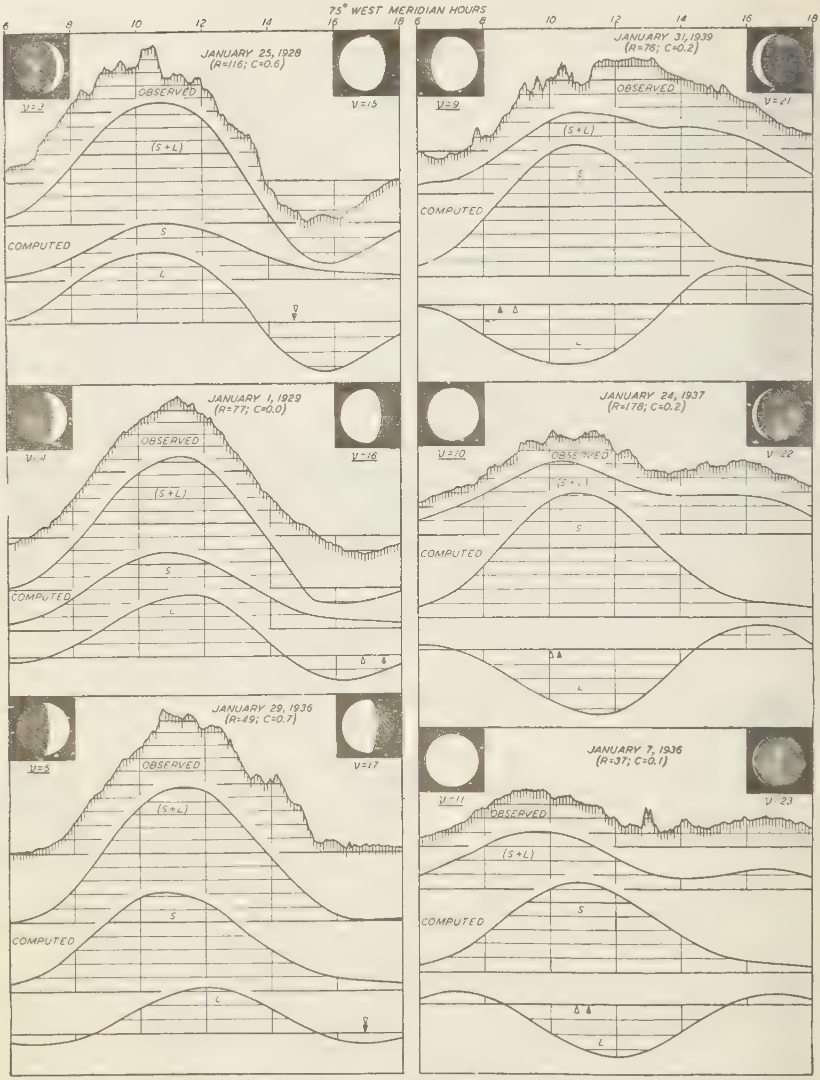


FIG. 5—FOR SUNSPOT-MAXIMUM; DEPARTURES FROM NIGHT-LEVEL, MAGNETIC HORIZONTAL FORCE, HUANCAYO, SELECTED QUIET DAYS WITH CONSPICUOUS GEOMAGNETIC TIDES IN JANUARY SHOWING INVERSION LEFT TO RIGHT OF TIDAL EFFECT WITH AGE (ν) OF MEAN MOON IN HOURS—UNDERSCORED FOR DATE GIVEN WHICH ALSO TYPIFIES (ν±12); R=SUNSPOT-NUMBER, C=MAGNETIC CHARACTER-FIGURE; UPPER AND LOWER TRANSITS: FOR MEAN MOON, FOR APPARENT MOON; SCALE 20γ PER DIVISION

S and L, representing the solar and lunar daily variations on that day. These three "computed" curves are those mentioned at the end of § 4, namely (σS*+λL*), σS*, and λL*. The determination of σ and λ will be discussed in § 6. Numerical values of σ and λ are given in Table 4; the somewhat hypothetical character of these magnification-factors and the "computed" curves should be remembered.

In Figures 2 to 5, each daily record is typical for the two values of ν—differing by 12 hours—indicated by the schematic disks of the Moon; the actual value of ν for the selected day is underlined. The curves for days with ν six hours apart, equivalent to a quarter-month, have been placed side by side; this juxtaposition emphasizes the striking contrast in the shapes of the "observed" curves. The "computed" curves show that this contrast might be ascribed to the inversion of the L-curve, since L*(ν) = −L*($\nu \pm 6$).

Table 4 gives also the angular distance $(s-p)$ of the mean Moon from its mean perigee, in hours of 15° each. It might have been expected, namely, that the "big-L-days" occur preferably about perigee, when $(s-p)=0$ hours; but this is not so as there are 13 such days with $(s-p)$ between 18 over perigee to 6 hours, and 11 days with $(s-p)$ between 6 over apogee to 18 hours. Later results (Part II) will indicate that the

TABLE 4—*Data for the days selected for the model-sets of "big-L-days"*

del =	Date	ν	(s-p)	Transit-times			R	C	σ	λ	Average departures			
				Transit	Mean	Apparent					Obs.	σS*	λL*	Res.
		h	h		h	h					γ	γ	γ	)
				Sunspot-minimum										
12	Jan, 17, 1923	0.02	6.94	Upper	12.19	12.62	0	0.3	1.14	6.58	56	48	49	13
13	Jan. 31, 1934	12.89	14.81	Lower	13.09	12.99	12	0.7	1.17	2.69	58	49	22	11
14	Jan. 19, 1923	1.65	8.69	Upper	13.88	14.23	0	0.1	0.82	4.15	72	34	41	19
15	Jan. 6, 1923	15.08	21.36	Lower	15.36	15.31	0	0.5	0.28	3.28	44	12	33	5
16	Jan. 22, 1923	4.09	11.30	Upper	16.40	16.40	7	0.9	1.30	2.72	81	55	24	12
17	Jan. 1, 1925	5.11	5.71	Upper	17.46	18.04	0	0.1	1.03	3.68	67	43	28	5
18	Jan. 2, 1925	5.92	6.58	Lower	5.88	6.42	0	0.1	1.51	2.57	73	64	19	7
19	Jan. 26, 1923	7.34	14.79	Lower	7.35	6.95	0	0.2	1.31	2.58	61	55	22	6
20	Jan. 29, 1935	19.91	18.99	Upper	7.94	7.18	11	0.3	1.21	4.00	46	50	39	14
21	Jan. 30, 1931	9.34	19.32	Lower	9.42	8.87	0	0.1	0.77	3.24	23	32	32	14
22	Jan. 19, 1924	10.29	14.61	Lower	10.40	10.19	0	0.5	1.08	4.13	24	46	36	5
23	Jan. 21, 1932	10.66	17.40	Lower	10.79	10.48	8	0.0	0.49	2.15	13	20	16	5
				Sunspot-maximum										
12	Jan. 29, 1926	12.50	12.00	Lower	12.69	12.87	51	0.5	1.03	1.50	65	73	24	17
13	Jan. 23, 1928	0.92	18.70	Upper	13.13	13.05	64	0.8	0.81	3.16	73	58	51	14
14	Jan. 8, 1939	14.22	1.23	Lower	14.47	14.80	78	0.8	0.89	3.13	90	63	54	16
15	Jan. 25, 1928	2.55	20.37	Upper	14.81	14.79	116	0.6	0.54	2.94	86	38	55	13
16	Jan. 1, 1929	16.49	6.24	Lower	16.82	17.46	77	0.0	0.79	2.24	88	56	41	6
17	Jan. 29, 1936	4.55	0.90	Upper	16.88	16.87	49	0.7	0.98	1.58	87	69	27	6
18	Jan. 21, 1926	6.00	5.04	Lower	5.96	6.44	103	0.0	0.96	2.51	84	68	40	10
19	Jan. 31, 1928	7.42	1.59	Lower	7.43	7.43	92	0.1	1.02	1.93	84	71	31	14
20	Jan. 15, 1939	19.91	7.33	Upper	7.94	8.23	86	0.3	1.40	1.82	102	99	31	11
21	Jan. 31, 1939	8.91	21.26	Lower	8.97	8.49	76	0.2	1.31	2.33	72	93	44	13
22	Jan. 24, 1937	9.94	3.33	Lower	10.04	10.30	178	0.2	1.23	2.08	87	87	38	7
23	Jan. 7, 1936	10.67	5.74	Lower	10.80	11.16	37	0.1	0.87	1.69	46	62	29	8

half of the anomalistic month in which L is systematically greater is centered at $(s-p)=4$ hours, after perigee; but there are exactly 12 days in each of the halves centered at $(s-p)=4$ and 16 hours. Thus, the influence of the lunar distance on the occurrence of "big-L-days" seems negligible, although, if more days had been selected, the influence of $(s-p)$ would probably have become clearer.

Transit-times, nearest to noon, of the mean Moon (calculated from ν) and of the apparent Moon (taken from the "American Ephemeris and Nautical Almanac") are given in Table 4 and indicated in Figures 2 to 5. They differ in one case by 0.76 hour = 46 minutes in time; these differences will be referred to in Part II.

§ 6. *An attempt to separate* S *and* L *on individual days*

The main features of a daily variation in H can be considered as given by a row of the 12 hourly means, or even six two-hour means, between 6^h and 18^h, expressed as departures from the night-level and corrected for non-cyclic variation. Such rows may express the "observed" curve on a particular day, or the average variations S* and L* for a specified time of the year and a certain average sunspot-number.

Table 3 gives S* and L* for January; how these values have been computed will be described in Part II. Only the "heart" of that Table—the 12 values from 6^h to 18^h in each column—will be used to determine the "magnification-factors" σ and λ expressing the observed curve as (S+L), with S $=\sigma$S*, L $=\lambda$L*.

As an example, consider the sunspot-minimum day January 29, 1935, with $\nu=20$, pictured in Figure 2; the hourly departures from the night-level are given in Table 5. The first two lines repeat, from Table 3, S* and L* (20) = L* (8) = −L* (2). The third line gives the "observed" departures. The approximation of the "observed" departures by a "synthetic" curve (σS*+λL*) requires the determination of σ and λ so that this equation is, as nearly as possible, valid for each hourly interval. In other words, 12 simultaneous equations for σ and λ must be solved, namely: $(+13.2\sigma-2.8\lambda)=0$; $(+28.3\sigma-6.2\lambda)=-5$; $(+56.9\sigma-10.0\lambda)=+2$; etc. The method of least squares yields $\sigma=1.21$, $\lambda=4.00$. The "synthetic" curve 1.21 S*+4.00 L* fits the "observed" curve well, as

Table 5—*Separation* (σS*+λL*) *for daily variation on January 29, 1935, horizontal intensity, Huancayo; departures from night-level*

Variation	Standard 75° west meridian hour											
	06–07	07–08	08–09	09–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
S*	+13.2	+28.3	+56.9	+84.8	+97.8	+91.6	+69.9	+37.0	+ 9.8	− 4.5	− 7.0	− 3.8
L*(ν=8)	− 2.8	− 6.2	−10.0	−13.2	−12.4	− 9.5	− 1.8	+ 8.3	+15.9	+18.1	+13.6	+ 6.3
Obs.	0	− 5	+ 2	+30	+73	+90	+92	+91	+79	+55	+29	+ 4
1.21 S*	+16	+34	+69	+103	+118	+111	+85	+45	+12	− 5	− 8	− 5
4.00 L*	−11	−25	−40	−53	−50	−38	− 7	+33	+64	+72	+54	+25
Synthetic	+ 5	+ 9	+29	+50	+68	+73	+78	+78	+76	+67	+46	+20
Residual	− 5	−14	−27	−20	+ 5	+17	+14	+13	+ 3	−12	−17	−16

shown by the "residuals," that is, the differences "observed" minus "synthetic." The relative importance of the superposed variations can be judged by the average absolute departures from the night-level, which are given in the last four columns of Table 4, namely, for the day considered in Table 5, 46γ for "observed," 50γ for σS^*, 39γ for λL^*, and **14γ** for the "residuals."

Because of the limitations to be discussed in § 7, the least-square methods were abbreviated in most cases, either by using two-hour means or by condensing the 12 hourly equations into two linear combinations favorable for the separation of σ and λ. In our example, by adding the four hourly departures from 8^h to 12^h, and the five hourly departures from 13^h to 18^h, the general equation $[(\sigma S^* + \lambda L^*) = \text{observed}]$ yields the combinations, expressed in the unit γ

$$(331.1\sigma - 45.1\lambda) = +195$$
$$(31.5\sigma + 62.2\lambda) = +258$$

with the solution $\sigma = 1.08$, $\lambda = 3.60$. These values give also quite a good fit, with the average residual raised only to 15γ from 14γ, as in the case of the orthodox least-square method.

Both Figure 2 and Table 5 show clearly that a part proportional to L^* is contained in the observed curve, and that it would be hopeless to regard the observed curve as a multiple of S^* alone; in fact, the least-square method—giving 0.78 S^* as the best fit of the observed curve by S^* alone—leaves residuals averaging as much as 34γ.

§ 7. *Uncertainties of this separation*

The separation of S and L in the daily variations on single days provides an approach to an accurate elimination of L, if S is to be used as a measure of solar wave-radiation W; furthermore, the high variability of L in itself deserves study. Therefore, the reliability of the computations described in § 6 will be briefly discussed.

(*a*) As shown in detail in Table 5, for each day with age ν, the two magnification-factors σ and λ give an equation

$$\text{Observed departure from night-level} = [\sigma S^* + \lambda L^*(\nu) + \text{residual}] \quad (7.1)$$

for each hourly interval, so that there are 12 such equations for each day. The magnitude of each term is given, in the last four columns of Table 4, by the average departures, taken without regard to sign. One might be inclined to judge the success of the separation by the relative magnitude of the average residuals compared with the smaller one of the averages for σS^* and λL^*—mostly the latter. This reasoning is, however, only correct as far as the representation of the observed curve by the "synthetic" curve $(\sigma S^* + \lambda L^*)$ is considered, but does not reflect on the reliability of the determination of σ and λ individually. Indeed, if, for a particular age of the Moon, L^* would have the same shape as S^* (say, $L^* = qS^*$, with q positive or negative), the approximation of the observed curve would determine $(\sigma + q\lambda)$ only, and all pairs of values σ and λ with the same value $(\sigma + q\lambda)$ would furnish the same synthetic curve.

In general, we may find, for each age ν of the Moon, a parameter $q(\nu)$ satisfying the 12 equations (one for each hourly interval)

$$L^*(\nu) = q(\nu)S^* + L^*_{\perp}(\nu) \quad (7.2)$$

by the condition that the sum of the squares of the 12 departures defining $L^*_\perp(\nu)$ should be as small as possible. This least-square adjustment (as well as other discussions in this section) can be pictured in an orthogonal coordinate-system of 12 dimensions, one for each hourly interval; each row in Table 5 defines the end-point of a vector from the origin; and equation (7.2) means that the vector $L^*(\nu)$ is represented as the sum of two vectors, one, $q(\nu)S^*$, in the direction of S^*, the other, $L^*_\perp(\nu)$, perpendicular to S^*. With (7.2), (7.1) becomes

$$\text{Observed departure} = [(\sigma+\lambda q)S^* + \lambda L^*_\perp(\nu) + \text{residual}] \qquad (7.3)$$

The average departures d for $L^*(\nu)$ and $d_\perp$ for $L^*_\perp(\nu)$ are given in the last two lines of Table 3, for $\nu=0$ to 5 hours; they are the same for the ages ν, $(\nu+6)$, $(\nu+12)$, and $(\nu+18)$ hours. The values $d_\perp$ show that the "significant" lunar variation $L^*_\perp(\nu)$ is greatest for $\nu=0$, 1, or 2 hours, and smallest for $\nu=4$ or 5 hours; these values confirm the impression, with respect to the degree of similarity, afforded by the curves marked S and L in Figures 2 to 5.

The values $\lambda d_\perp$, which are the average departures for $\lambda L^*_\perp(\nu)$, should be compared with the average residuals. In one case (sunspot-minimum, $\nu=4$) the average residual $(=12\gamma)$ exceeds $\lambda d_\perp$ $(=10\gamma)$. Table 6 summarizes the magnitudes of the average departures given in the last four columns of Table 4, and supplements them by those for $\lambda L^*_\perp(\nu)$; the values for sunspot-minimum and maximum and for three consecutive values of ν have been combined. For the "unfavorable" ages—around ν or $(\nu-12)=4$ and 10 hours the average departures for the significant lunar variation $\lambda L^*_\perp$ are reduced to nearly one-half those for λL, but remain still about twice as large as the average residuals.

TABLE 6—*Average departures from night-level for the days given in Table 4*

Age ν or $(\nu-12)$	Observed	σS^*	λL^*	$\lambda L^*_\perp$	Residual
hours	γ	γ	γ	γ	γ
0, 1, 2	69	54	40	36	15
3, 4, 5	76	46	35	19	8
6, 7, 8	75	68	30	27	10
9, 10, 11	44	57	32	17	9
All	66	56	34	25	10

(*b*) The average variations S^* and L^* have been chosen rather rigidly. The restriction to two average sunspot-numbers R is not serious as far as the approximation is concerned, because the change of S^* and L^* with R is more an increase in the amplitude, and less a deformation of the shape of the daily curve; more detailed choice of S^* and L^* with regard to R would therefore have changed σ and λ, but not the residuals. The restriction of L^* to round values of ν, the neglect of the lunar-distance effects, and of the seasonal changes of S^* and L^* between January 1 and 31 may have caused part of the residuals; but since the computations were mainly illustrative it was not thought worth while to go into greater detail.

σ and λ have been considered constant throughout the day. This assumption was necessary if the computations should not become arbitrary; but on certain days the records give the impression that the magnification of S^* and L^* has changed in the course of the day. This appears possible; sudden S_q-augmentations have been shown by McNish to be caused by solar flares, and less abrupt changes of the solar wave-radiation W in the course of 12 hours are also not improbable.

Finally, S and L vary from day to day not only as differently magnified curves S^* and L^*, but the shape of the curves may change too. Consider, for instance, the extreme case that, on a certain day, S is the S^*-curve shifted a whole hour earlier; in other words, $S = \iota(S^* + \delta S^*)$, where δS^* is the change of S^* from one hour to the next. The rigid calculation of § 6 would interpret δS^* as λL^*. Looking through the columns in Table 3, the changes δS^* from hour to hour resemble $L^*(\nu)$ most for $\nu = 1$; in fact, for sunspot-maximum, the least-square method gives $\delta S^* = 1.41\ L^*(1)$. Therefore, just at that age ν when S^* resembles L^* least, and when the corresponding large significant variation $L^*_\perp$ makes the separation appear most hopeful, δS^* resembles L^* most, so that a shift in S could be mistaken for L; vice versa, for $\nu = 4$, when S^* resembles L^* most, δS^* resembles L^* least.

(*c*) Summarizing, it seems that various factors make the separation of S and L on single days somewhat uncertain, although approximative estimates are possible, and it remains certain that L varies considerably in intensity from day to day and is often, on the "big-L-days" in January, of a magnitude equal to S. Additional evidence that L seems to vary relatively more than S will be indicated later (§ 16*b*); a comparative study of June magnetograms—when L is smallest—seems desirable.

§ 8. *Some general viewpoints on the study of daily variations*

This paper deals mainly with the effect of the "mean Moon" or, referring to the dynamo theory of L, with the geomagnetic effects of the main lunar semidiurnal partial tide M_2 in the potential of the tide-generating forces [8, 9], and (in Part II) with the effects of the changes in the Moon's distance from the Earth, partial tides N_2, L_2, and $2N$. Each of these gravitational partial tides M_2, N_2, etc., gives rise to a geomagnetic partial tide, $L(M_2)$, $L(N_2)$, etc., so to say. The restriction to the partial tides M_2, N_2, L_2, $2N$ is preliminary; so far, only M_2 and N_2 have been recognized in atmospheric and geomagnetic tides, and the search for other terms, especially diurnal waves, has had little success.

In the harmonic analysis of ocean tides, in which M_2 predominates, the data are usually divided into lunar days, and this practice has often been adopted for geomagnetic studies of L. In this paper, however, we will keep to the solar days, agreeing with Chapman and Miller [3]; in the night-hours, both S and L are small, so that midnight is convenient for dividing the material. L and S, so to say, start afresh every morning. Because the magnetic character-figure C refers to Greenwich days, the actual dividing point in the computations has been Greenwich midnight, or 19^h standard 75° west meridian time.

In each single interval of 24 hours, a magnetic-force component is a function of time, $f(t)$, different each day. It can be conceived [1] as a superposition of three parts

$$f(t) = (S_q + L + D) \tag{8.1}$$

which may be studied separately. The intensity of the disturbance-variation D depends on that of the solar corpuscular radiation P. On quiet days D consists of a recovery, a non-cyclic variation which can be easily eliminated. What "quiet days" are, in the sense that D is negligible, depends on the station, on the magnetic element, and on the problem considered. For Huancayo, near the equator, days with $C<1.2$ will be found (§ 13) to be practically free of S_D, which is that part of D which would mask S_q and L; only the irregular part of D increases with C from 0.0 to 1.1 (§ 13). The restriction to days with $C<1.2$ eliminates therefore S_D.

Both S and L in Huancayo H on such days can be expected to depend on the solar wave-radiation W, approximated by the relative sunspot-number R, and on the season. L, moreover, depends on the mean Moon's motion, here characterized by its age ν and its angular distance $(s-p)$ from its perigee.

The perfect result of a study of S and L would provide a table from which S and L could be predicted for each combination of fundamental variables, that is, for each calendar date of the year, and for every possible value of R, ν, $(s-p)$, and other parameters, even perhaps accounting for possible after-effects. This ideal could be reached only if unlimited observational data were available; and even then only in the sense that the predictions for S and L would be consistent in themselves, that is, two predictions for the same combination of variables, derived from different series of observations of sufficient length, would be equal. Nevertheless, the actual daily curve would still show a residual, compared with the predicted (S+L). This residual would be partly due to D, but also partly to an actual variability of S and L which expresses the fact that the fundamental variables considered do not exhaust all the variable circumstances—irregularities in the ionization and in the air-motion—on which S and L depend. For shortness, we distinguish the "*systematic*" dependence of S and L on the fundamental variables from their "*irregular*" variability.

The practical approach to the perfect result expressing the systematic dependence is, of course, the usual method of forming groups of days for which the fundamental values lie between chosen limits, and to compute averages for S and L for each group, in the expectation that the irregular variability for group-averages will be smaller than that for single days. If this variability is measured by the average residual, as in § 7, it will, in an average for a group of n days, be reduced in the ratio $\sqrt{\epsilon(n)/n}$, where $\epsilon(n)$ is a parameter measuring quasi-persistence, that is, the interdependence of consecutive individual days [10]; $\epsilon(n)=1$ if the days are statistically independent.

The choice of groups has to reconcile two demands: The group-limits must be so wide that the number of days combined is sufficiently large to reduce the irregular variability in the average; but at the same time they should be so small that enough groups can be formed to study the systematic dependence of S and L—preferably so small that the systematic dependence of S and L within the group-limits is practically linear so that the average S and L can be considered as the systematic S and L for the averages of the fundamental variables for that group.

It is practical to start with small groups, to study the variability of the averages, and then combine them into sufficiently large groups which show the systematic dependence clearly enough. Groups formed in this paper have been described in § 2. Results for small groups will be mostly expressed in tabular form in order to allow the combination with results from years to come or from other observations, while results for large groups, as the basis for discussing systematic features, will be given graphically.

§ 9. *Chambers's lunisolar variations, and Chapman's phase-law*

For a definite station, magnetic element, season, and sunspot-number, Chambers [11] expressed L, in solar time t, for any age ν, by

$$\mathsf{L}(\nu)\equiv[a(t)\cos 2\nu+b(t)\sin 2\nu] \tag{9.1}$$

so that $\mathsf{L}(\nu)$ is determined by $\mathsf{L}(0)=a(t)$ at New Moon, and $\mathsf{L}(3)$ $b(t)$ at one-eighth phase. If $a(t)$ and $b(t)$ are expressed in hourly means, L is determined by 48 values. With ordinary harmonic analysis, the sine-waves for periods of 24, 12, 8, and 6 hours in $a(t)$ and $b(t)$ would be determined by $2\times2\times4=16$ parameters. [If $a(t)$ and $b(t)$ contain constant terms, there would be two more parameters. This possibility has not been considered before; it postulates that the ordinary daily means change with the age ν of the Moon in a semimonthly wave, which will be discussed in Part II.]

Chapman reduced the number of parameters to eight, namely, four amplitudes c_σ and four phase-angles ϵ, in his phase-law, expressed either in mean lunar time τ or mean solar time t (in the latter case neglecting the small change of the age in the course of the day)

$$\mathsf{L}(\nu)\equiv\sum_{\sigma=1}^{4} c_\sigma \sin[\sigma\tau+\epsilon_\sigma+(\sigma-2)\nu]=\Sigma c_\sigma \sin[\sigma t+\epsilon_\sigma-2\nu] \tag{9.2}$$

(9.2) is a special case of (9.1), expressing the two sets of harmonic coefficients for $a(t)$ and $b(t)$ by one set of coefficients, c_σ and ϵ_σ, namely,

$$a(t)=\Sigma c_\sigma \sin(\sigma t+\epsilon_\sigma),\quad b(t)=-\Sigma c_\sigma\cos(\sigma t+\epsilon_\sigma) \tag{9.3}$$

In this paper, we shall use mainly the more general expression (9.1); but the validity of (9.2) will also be tested (Part II), and a new general expression for $\mathsf{L}(\nu)$ will be introduced.

§ 10. *Two ways of computing* L

Consider a lunar variation L expressed in hourly means. Each hourly mean depends then on variables which stand in the relation 2(4); the possible independent pairings are (t, τ), (t, ν), or (τ, ν), all of which have been used. We choose (t, ν), as in (9.1).

The analysis of a function of two variables from observed data may be begun by regarding one variable as a parameter (kept constant) and studying the variation with the other variable. Which of the two variables is chosen as parameter in this initial step of the analysis, should be irrelevant for the final result. In the case of $\mathsf{L}(t, \nu)$, the two possibilities are to regard t as parameter and to study $\mathsf{L}(\nu)$, the variation with ν (*fixed-hour method* described in [1] as van der Stok's method), or to regard ν as a parameter and to study $\mathsf{L}(t)$, the variation with t (*fixed-*

age method described in [1] as Broun's method). Both ways have been used by various authors in geophysical problems, also their equivalents with L expressed by (τ, ν) or (t, τ). The fixed-age method has been furthest developed in a recent paper by S. Chapman and J. C. P. Miller [3]; the fixed-hour method has been recently applied by M. Bossolasco [18], J. Egedal [19], and W. J. Rooney [20].

In geomagnetism, the two methods are not equally effective with regard to the elimination of irregular disturbance-effects. The fixed-age method seems preferable, because it removes from L(t) automatically the average effect D_m of the storm-time variation (ring-current effect) on the daily means, and can easily be modified to eliminate the non-cyclic variation too. With the fixed-hour method, L(ν) appears as a lunar semimonthly wave (9.1) in each hourly mean; the fluctuations of the daily means caused by D_m will, however, introduce considerable semimonthly waves of a random nature, which will mask L(ν) unless they are eliminated, for instance, by expressing the original hourly means as departures from the daily mean or from the night-level.

§ 11. *Use of ranges*

The statistical disadvantage of the fixed-hour method lies in the fact that it judges L(ν) by the changes in hourly means *from day to day*—which are superposed on much greater irregular changes—while the fixed-age method L(t) judges L by the changes *from hour to hour*—from which the superposed large changes due to S can be eliminated because of their regularity. The weakness of the fixed-hour method appears particularly pronounced in the allied problem of computing the atmospheric tides from readings of barometric pressure at ground-stations, because the great pressure-waves connected with the weather-changes introduce semimonthly waves of much greater amplitudes than L, even at equatorial stations. Only hourly or bihourly readings of recording barographs, treated by the fixed-age method, seemed adequate. With the usual three barometer-readings per day at climatological stations, it appeared hopeless to attempt a calculation by the fixed-hour method until it was realized [12] that the effect of these long-period weather-waves can be neutralized by studying L(ν) in the *changes* of pressure between two successive readings. The experience gained in these pressure-studies led to the extraction of L from geomagnetic daily ranges, originally introduced for the purpose of measuring S.

§ 12. *The ranges A and A_S*

Various kinds of daily ranges have been used to indicate the magnitude of the daily curve $f(t)$ as analyzed in (8.1). In the international scheme of the "numerical character" which operated from 1930 to 1939, R_H was the difference between the highest and lowest *instantaneous* values of H in a Greenwich day. R_H is—as was intended—much affected by D; and so is, although less, a range derived from the highest and lowest hourly means. For a range-definition suitable for measuring the intensity of S and rather independent of D, the shape of the S-curve in Huancayo H suggests the rise of the noon-level of H over its night-level [13], so that the range is expressed by

$$A = (\text{average from } 9^h \text{ to } 14^h) \text{ minus } (\text{average from } 0^h \text{ to } 5^h) \quad (12.1)$$

taken with sign. More exactly, A is the excess of the average H for (9^h to 14^h) over the night-level corrected for non-cyclic change, as shown in the reproduction of a magnetogram in Figure 6. The non-cyclic

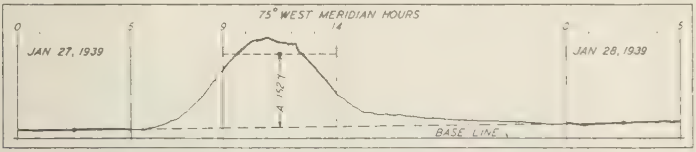


FIG. 6—DEFINITION OF RANGE A IN HORIZONTAL INTENSITY AT HUANCAYO

change is eliminated by measuring A from a straight line connecting consecutive averages for (0^h to 5^h). Since the centers of the five-hour intervals are at $2^h.5$ and $11^h.5$, nine hours apart—incidentally symmetrical to 7^h, or Greenwich noon—the numerical correction for non-cyclic change is easily made. If N' and N'' are the values of the consecutive night-levels (0^h to 5^h), the corrected night-level is $[N'+(9/24)(N''-N')]$; this is subtracted from the noon-level (9^h to 14^h) to give A. Of course, if one of the night-levels is highly disturbed—for instance, if a storm beginning after 14^h depresses N''—this correction must not be applied schematically; therefore, in such cases, the non-cyclic correction is estimated. This summary procedure is justified since the effect of the non-cyclic change on A amounts to only a few per cent for days with $C<1.2$. To show the order of magnitude: In the (rather disturbed) months January 1926 and January 1938, the average non-cyclic correction [that is, $(9/24)(N''-N')$, taken without regard to sign] was 4.0γ, to be compared with an average $A=118\gamma$; in the (quiet) months January 1931 and 1932, the corresponding figures were 2.0γ and 76γ.

Such ranges A were computed for all days with $C<1.2$ for the whole available series, March 1922 to October 1939. For the months December, January, February, in the sunspot-maximum (Table 1), A was also computed for the days with C between 1.2 and 2.0.

Daily ranges of H which are obtained by eliminating the effect of L from A (see § 18) will be called A_S, since they can be used to measure the intensity of S.

§ 13. *Absence of appreciable disturbance-effects in the ranges A*

Averages were formed for the two kinds of ranges A and R_H for groups of days with increasing magnetic character-figure C, as explained in § 2 (10), and collected in Table 7. The first row refers to sunspot-

TABLE 7—*Daily ranges A (of five-hour means) and R_H (of instantaneous values), horizontal intensity, Huancayo; averages for four or five classes of days q_0, q_1, q_2, q_3 and d, in the order of increasing international character-figure C*

Averages for months	Ranges A on days					Ranges R_H on days					Ratios (R_H/A) on days				
	q_0	q_1	q_2	q_3	d	q_0	q_1	q_2	q_3	d	q_0	q_1	q_2	q_3	d
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ					
quinoxes, 1931–34	92	86	90	86	....	135	137	147	153	....	1.47	1.59	1.63	1.78	
quinoxes, 1936–39	142	140	139	142	....	188	200	204	223	....	1.32	1.43	1.47	1.57	
ec, Jan, Feb, 1935–39	125	125	132	131	118	173	179	205	219	295	1.38	1.43	1.55	1.67	2.50

minimum, the second and third rows to sunspot-maximum. Of course, $R_H > A$ always; but while R_H increases distinctly with C, A remains practically constant, at least for the first four groups q_0 to q_3, which are subdivisions of all days with $C < 1.2$. The small differences, in each row, between the average A for groups q_0 to q_3 are of the order of the probable errors and therefore statistically not significant.

A systematic change of A with C might have been expected for two reasons: A would *increase* with C, if the solar wave-radiation W should increase parallel with the increase of solar corpuscular radiation P indicated by C; but A would *decrease* with C as soon as the solar daily disturbance variation S_D becomes appreciable, because the shape of the S_D-curve makes the range A as defined by (12.1) negative. An independent estimate of A for S_D is possible for the material on S_q (from the five international quiet days per month, our q_0-days) and ($S_q + S_D$) (from the five international disturbed days per month) for Huancayo H in the average for the sunspot-maximum years 1926-29 ($R = 69$) as published in graphical form [13]; the average character-figures for these international quiet and disturbed days are about $C = 0.1$ and $C = 1.5$. The average ranges A are contained in Table 8. The decrease of A due to S_D appears in Table 7 between the q_3-days and the d-days.

TABLE 8—*Average ranges A of five-hour means in horizontal intensity, Huancayo sunspot-maximum, years 1926-29*

Item	December-solstice	Equinoxes	June-solstice
	γ	γ	γ
International disturbed days ($S_q + S_D$)	107.1	116.8	90.9
International quiet days S_q	119.1	130.3	93.4
Disturbance daily variation S_D	−12.0	−13.5	−2.5

There is a theoretical possibility that the two influences of solar corpuscular radiation P on the range A could both be strong, but just neutralized in the averages: The increase of A due to a simultaneous increase of W correlated with an increase in P, might just counterbalance the decrease of A due to the direct effect of P, namely, S_D. This is, however, quite unlikely, because the effect, on A, of S_D, even for rather high disturbance, is not so large as the change of A with the sunspot-cycle. It seems therefore safe to conclude that, as far as changes of the range A on days with $C < 1.2$ in the course of the month are concerned, an increase of P has no appreciable effect on S. This fact makes A more valuable as a measure for solar wave-radiation W. It further obviates, in computations of L, the necessity to consider subdivisions (groups q_0, q_1, q_2, q_3) of the quiet days since it is certain that S is systematically the same for all these days with $C < 1.2$. That this holds also for L will not be tested here directly, but may be inferred from the results of § 17.

§ 14. *Computation of the lunar semimonthly waves in the ranges A*

The daily ranges A on days with $C < 1.2$ are written in 12 columns, for ν or $(\nu - 12) = 0, 1, 2, \ldots 11$ hours, as indicated in the sample

TABLE 9—*Computation of lunar semimonthly wave in daily ranges H, Huancayo, February, sunspot-group Max_4 for days with C less than 1*

February in year	ν in hours 0 / 12	1 / 13	2 / 14	3 / 15	4 / 16	5 / 17	6 / 18	7 / 19	8 / 20	9 / 21	10 / 22	11 / 23
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1927	52*p*	125	109	142	220*p*	185	.....	.....	94	90*p*	144	134
1927	146	134*p*	124	111	130	145*p*	.....	132	135	120	129	....
1930	.....	.....	150	154	.....	192	124*p*	109	55	131	96*p*	..
1930	.....	.....	.....	130	145	130	105	65*p*	44	96	.....	96*p*
1937	.....	163*p*	168	191	148	187*p*	176	.....	119	128*p*	161	206
1937	211	241	192*p*	.....	223	213	.....	.....	.....	118*p*	52	.....
1938	.....	111	161	185	148*p*	.....	.....	.....	.....	.....	112	158
1938	166	133	175	134	152	149*p*	110	58	78	96	85	139
1939	133*p*	154	131	160	146	.....	179	155	134	.....	.....	76
1939	127	112	.....	191	170	143	158	108*p*	75	94	100	106
Average	139	147	151	155	165	168	142	104	92	109	110	131
Wave	+5	+13	+17	+21	+31	+34	+8	−30	−42	−25	−24	−3

Result: Average $A = 134\gamma$; semimonthly wave $= (0.7\gamma \cos 2\nu + 31.1\gamma \sin 2\nu)$
$= 31.1\gamma \sin (2\nu + 1°)$

Table 9. For pairs of successive undisturbed days with equal integral values of ν [see § 2 (4)], the average A has been entered (marked p in Table 9); but for the months with 30 or 31 days, where days with the same ν occur at the beginning and at the end of the month, the ranges A for these days are entered singly. The blank spaces indicate, of course, disturbed days, or the few days for which the magnetogram was defective. The averages are formed *without* regard to the letters p; it is true that this gives these average ranges for successive pairs of days not the weight they deserve, but, because of quasi-persistence in S, this relative weight, compared with A from single days, is certainly less than 2, and experience showed that a more detailed treatment would hardly improve the accuracy of the semi-monthly waves.

The line of averages for the 12 columns is then harmonically analyzed to yield the semi-monthly wave

$$a_A \cos 2\nu + b_A \sin 2\nu = c_A \sin (2\nu + \alpha_A) \qquad (14.1)$$

If the analyzed values were averages for intervals of 15° in ν, or 30° in 2ν—because ν is rounded off to the nearest hour—the effect of this "smoothing" should be corrected, in a_A, b_A, and c_A, by applying the factor $[(\pi/12)/\sin (\pi/12)] = 1.012$. Actually, since pairs of successive undisturbed days with equal ν have been given half weight, this factor should be somewhat smaller; we choose—by a somewhat lengthy argument which need not be given here—the factor 1.010, which will be correct to one part in 1,000, even though it depends on the percentage of pairs in which only one day is undisturbed, and will therefore vary somewhat with the sunspot-cycle.

The coefficients a_A, b_A, are given in Table 10-A. The average coefficients 1922-39 for each month, marked "All", are means of the coefficients for the four sunspot-groups, weighted proportional to the number of months in the groups (see Table 1), for instance, for January, All =

[(5 Min_1+3 Min_2+4 Max_3+5 Max_4)/17]; they represent therefore the average semimonthly wave computed from all the days with $C<1.2$ without distinction.

How well the lunar variations in the ranges A fit semimonthly sine-waves is shown in Figure 8: The dots near the curve at the center give

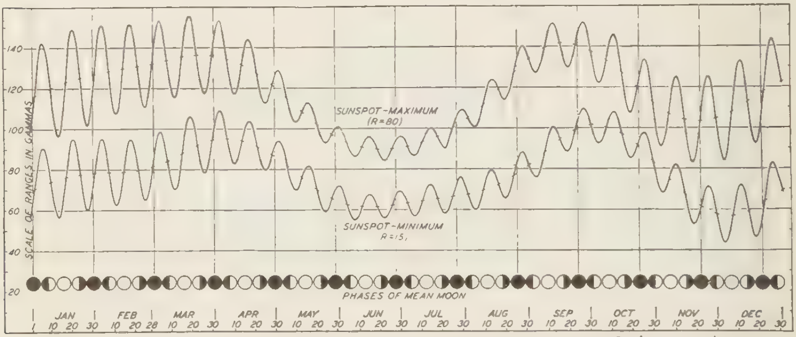


FIG. 7—YEARLY AND HALF LUNAR-MONTH VARIATIONS OF QUIET-DAY RANGES (1922-1939) IN MAGNETIC HORIZONTAL FORCE, HUANCAYO, REFERRED TO NEW MOON ON JANUARY 1

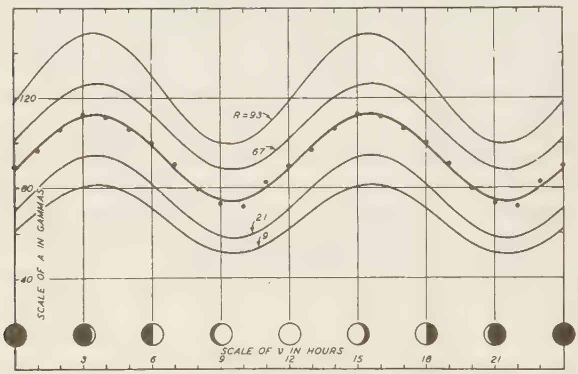


FIG. 8—VARIATION OF DAILY RANGES A IN HORIZONTAL INTENSITY AT HUANCAYO, DECEMBER SOLSTICE, 1922-39, WITH AGE ν OF MOON AND RELATIVE SUNSPOT-NUMBER R [OBSERVED TOTAL AVERAGES (DOTS) AND SEMIMONTHLY SINE-WAVES]

the actual averages of A obtained by grouping all ranges A in the months November to February, 1922-39, according to the age of the Moon [for ν and ($\nu \pm 12$) hours averaged promiscuously], and the curve is the semimonthly sine-wave obtained by harmonic analysis. Figure 8 gives also the lunar semimonthly sine-waves in A in the December solstice for four groups according to the sunspot-number R.

The values a_A and b_A in Table 10-A are remarkably regular, showing how clearly the influence of ⅼ on A can be recognized in as little material as three to five months. Of the $4 \times 12 = 48$ independent values of b_A in Table 10-A, all but two are positive. In order to reduce the "accidental" scattering still further, Tables 10-B to 10-E, which are all based

on Table 10-*A*, give averaged and smoothed results. Figure 7 illustrates the main results in two schematic curves, for sunspot-maximum and sunspot-minimum, showing how the range *A* would vary, in the course of the year, under the combined influence of L and of the season on S, in a year supposed to begin with new Moon on January 1. The vertical lines indicate the epochs of new Moon. The change in amplitude c_A of the semimonthly wave from its greatest value in January to its smallest value in June is quite marked; in addition, there is a shift in phase, with the crest of the wave occurring earlier (with respect to new and full Moon) in June than in January. The seasonal change of *A* due to S is obviously different in character from the seasonal change of L (see § 16, *a*).

TABLE 10—*Lunar semimonthly waves* [$a_A \cos 2\nu + b_A \sin 2\nu = c_A\ (2\nu + \alpha_A)$] *in daily ranges A in horizontal force at Huancayo, and averages for* A_S = *daily ranges corrected for lunar influence and R = Zürich relative sunspot-numbers*

TABLE 10-*A*—*Original results for monthly groups*

Sunspot-group	a_A	b_A	a_A	b_A	a_A	b_A	a_A	b_A	a_A	b_A	a_A	b_A
	January		February		March		April		May		June	
$_1$, in 0.1γ	−142	+124	− 22	+189	+ 18	+ 66	+ 66	+164	+ 23	+ 62	+ 55	+ 42
$_2$, in 0.1γ	− 52	+136	− 13	+295	+ 52	+141	+ 67	+113	+ 61	+ 61	+ 47	− 16
$_3$, in 0.1γ	−189	+192	+ 6	+160	+ 77	+178	− 26	+137	+ 59	+ 48	+ 22	+ 26
$_4$, in 0.1γ	−261	+229	+ 7	+311	+ 94	+202	+ 42	+143	+ 29	+ 42	+ 87	− 16
ll, in 0.1γ	−172	+173	− 5	+237	+ 60	+145	+ 39	+141	+ 41	+ 53	+ 55	+ 9
ll, c_A, in 0.1γ	244	......	237	......	157	......	146	......	67	......	56	......
ll, α_A, in °	......	315	......	359	......	22	......	15	......	38	......	81
	July		August		September		October		November		December	
$_1$, in 0.1γ	+ 84	+ 67	+ 59	+ 71	+ 50	+104	+ 46	+ 50	+ 10	+144	− 47	+125
$_2$, in 0.1γ	− 4	+ 40	+ 29	+111	+ 8	+ 66	+ 87	+ 28	− 79	+ 48	− 61	+203
$_3$, in 0.1γ	+ 53	+ 23	+ 37	+ 24	+118	+ 18	+ 14	+142	+ 2	+166	− 63	+217
$_4$, in 0.1γ	+ 21	+ 66	+ 46	+ 50	+110	+ 59	+ 3	+203	+ 79	+199	− 31	+243
ll, in 0.1γ	+ 40	+ 51	+ 44	+ 64	+ 72	+ 64	+ 36	+108	+ 13	+148	− 49	+195
ll, c_A, in 0.1γ	65	......	78	......	97	......	114	......	149	......	201	......
ll, α_A, in °	......	38	......	35	......	48	......	18	......	5	......	346

TABLE 10-*B*—*Results for seasonal groups, derived from Table 10-A*

Sunspot-group	December-solstice				Equinoxes				June-solstice			
	R	A_S	c_A	α_A	R	A_S	c_A	α_A	R	A_S	c_A	α_A
		0.1γ	0.1γ	°		0.1γ	0.1γ	°		0.1γ	0.1γ	°
Min$_1$	9	660	154	341	7	880	106	25	8	648	82	43
Min$_2$	20	775	178	343	28	980	102	32	26	734	59	34
Max$_3$	67	1082	194	342	57	1219	128	21	58	874	52	55
Max$_4$	93	1236	251	348	91	1430	164	22	104	1068	58	52
All	50	949	195	344	46	1130	126	25	50	834	63	46

TABLE 10-C—*Smoothed results for monthly groups, obtained from Table 10-A*

[The smoothed coefficients a_A, b_A for groups were obtained as follows: "Feb." = (January + 2 February + March)/4, etc.; "Min_1" = (2 Min_1 + Min_2)/3; "Min_2" = (Min_1 + Min_2 + Max_3)/3; "Max_3" = (Min_2 + Max_3 + Max_4)/3; "Max_4" = (Max_3 + 2 Max_4)/3]

Sunspot-group	c_A	α_A	c_A	α_A	c_A	α_A	c_A	α_A	c_A	α_A	c_A	α_A
	0.1γ	°	0.1γ	°	0.1γ	°	0.1γ	°	0.1γ	°	0.1γ	°
	"January"		"February"		"March"		"April"		"May"		"June"	
"Min_1"	170	334	170	350	140	11	122	24	88	33	65	49
"Min_2"	193	335	179	352	155	12	122	20	80	33	56	52
"Max_3"	232	336	219	354	188	14	130	20	72	38	49	63
"Max_4"	272	332	252	352	211	14	136	17	70	35	55	65
All	219	333	200	351	171	13	128	21	78	35	57	58
	"July"		"August"		"September"		"October"		"November"		"December"	
"Min_1"	77	43	92	31	89	30	80	25	104	356	148	337
"Min_2"	61	45	77	38	85	38	89	23	124	354	171	337
"Max_3"	49	43	70	39	91	40	114	19	155	359	203	340
"Max_4"	56	50	73	52	104	41	157	17	199	5	228	343
All	63	46	79	39	94	37	114	20	150	1	189	340

TABLE 10-D—*Smoothed results for seasonal groups, obtained from Table 10-B*

[The coefficients a_A, b_A were smoothed between sunspot-groups as in Table 10-*C*, but the seasons were kept separate]

Sunspot-group	December-solstice				Equinoxes				June-solstice			
	a_A	b_A	c_A	α_A	a_A	b_A	c_A	α_A	a_A	b_A	c_A	α_A
	0.1γ	0.1γ	0.1γ	°	0.1γ	0.1γ	0.1γ	°	0.1γ	0.1γ	0.1γ	°
"Min_1"	−50	+154	162	342	+48	+ 93	105	27	+48	+56	74	41
"Min_2"	−54	+167	176	342	+48	+101	112	25	+44	+46	64	44
"Max_3"	−55	+200	207	345	+54	+119	130	24	+41	+38	56	47
"Max_4"	−55	+225	232	346	+57	+141	152	22	+45	+34	56	53
All	−53	+188	195	344	+52	+114	126	25	+45	+44	63	46

TABLE 10-*E*—*Ratios (1000 c_A/A_S) for smoothed amplitudes c_A (Tables 10-C and 10-D) and similarly smoothed daily ranges A_S*

Sunspot-group	Smoothed monthly results												Seasonal grou[illegible]		
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Dec.-solst.	Equi-nox	Ju[illegible] so[illegible]
"Min_1"	233	210	159	143	119	102	118	121	102	93	146	224	232	115	[illegible]
"Min_2"	222	188	153	127	96	78	84	92	88	92	148	214	210	109	[illegible]
"Max_3"	219	192	159	116	75	58	56	70	78	97	149	205	201	107	[illegible]
"Max_4"	223	194	158	108	65	57	57	65	80	118	169	200	196	112	[illegible]
"All"	224	189	155	122	86	72	78	85	87	105	158	209	206	111	[illegible]

§ 15. *Estimates for scattering*

(*a*) Suppose the series of observations were infinitely long, and the coefficients a_A, b_A for the lunar semimonthly wave in A were calculated for each individual calendar month. Collecting all the months of January with the same sunspot-number, say $R=0$, we should find that the coefficients (a_A, b_A) would not be identical for each month, but would differ, by residual coefficients $(\triangle a_A, \triangle b_A)$, say, from the total average for all months of January with $R=0$. This scattering in the results for the individual months can be pictured in a cloud of points [14] in the harmonic dial, in which the wave in each individual month is represented as a point (end of a vector) with a_A, b_A as plane rectangular coordinates, a_A upward, b_A toward the right; and the amount of scattering can be measured by the probable error-radius ρ_0 of the cloud, defined as 0.833 times the standard deviation, or square-root of the variance which is the average $(\triangle a^2{}_A+\triangle b^2{}_A)$ The scattering for average waves derived from n months (of January, with $R=0$) is then pictured by a point-cloud in which the probable error-radius is $(\rho_0/\sqrt{n})$. The probable error-circle, described with the probable-error radius around the long-time average, divides, under ideal conditions, the cloud of points into two halves, with equal number of points inside and outside; but in this paper, the probable-error is just a constant fraction of the standard deviation.

(*b*) Since the error determination is only of secondary importance, and since the observational material is limited, the orthodox scheme just described was replaced by the following, less laborious procedure.

(α) The number of different "elementary" probable-error radii ρ_0 (measuring the irregular scattering of semimonthly sine-waves calculated from individual months) was reduced to six, namely, one for all the months in each of the three four-monthly seasons, for sunspot-minimum and sunspot-maximum.

(β) Each difference between an "original" wave (in Tables 10-*A* or 10-*B*) and a "smoothed" wave (in Tables 10-*C* and 10-*D*) is used to estimate ρ_0.

(γ) We assume, for simplicity, that the clouds of points for individual months with equal R are circular. As far as the evidence goes, it seems to indicate that, if the clouds are ellipsoidal, their major axis may lie along the average vector, that is, the amplitudes scatter more than the phase-angles; this would modify the considerations in the following subsections (*e*) and (*f*).

(*c*) The actual calculation is based on the fact that $\rho^2{}_0$, as defined above, is a fixed multiple of the variance, or square of the standard deviation. If x, y, . . . , are independent statistical variables with the probable error ρ_x, ρ_y, . . . , then the square of the probable error of a linear combination

$$jx+ky+\ldots \tag{15.1}$$

is

$$j^2\rho^2{}_x+k^2\rho^2{}_y+\ldots, \tag{15.2}$$

this "law of propagation of errors" holds also for two-dimensional errors, as in the case of the clouds in the harmonic dial, and implies the ordinary law that arithmetical averages of n values, with equal individual probable errors ρ, have the probable error

$$\rho/\sqrt{n} \tag{15.3}$$

Let for the moment the four pairs of original coefficients (a_A, b_A) in Table 10-*A* for the four sunspot-groups in each month be referred to as Jan_1, Jan_2, Jan_3, Jan_4, etc., while the smoothed values may be "Jan_1", "Jan_2", etc. For instance, in the unit γ

$\mathrm{Jan}_1 \backsim (-14.2, +12.4)$, according to Table 10-*A*

"Jan_1" $\backsim (-7.4, +15.3)$, according to the values c_A, α_A in Table 10-*C*

The difference is $(-6.8, -2.9)$. In a long-time average, this difference ("Jan_1"—Jan_1) is to be expected much smaller. Neglecting this small systematic difference, the square amplitude, $(6.8^2+2.9^2)=7.4^2$, can be considered as an estimate for the variance of the difference, and 0.833×7.4 as an estimate for the probable error.

Now, according to the double smoothing procedure explained in § 2 (7) and (11), or in Table 10-*C*

$$\text{"Jan}_1\text{"} \backsim [(2\ \mathrm{Dec}_1+4\ \mathrm{Jan}_1+2\ \mathrm{Feb}_1+\mathrm{Dec}_2+2\ \mathrm{Jan}_2+\mathrm{Feb}_2)/12] \tag{15.4}$$

and

$$(\text{"Jan}_1\text{"}-\mathrm{Jan}_1) \backsim [(2\ \mathrm{Dec}_1-8\ \mathrm{Jan}_1+2\ \mathrm{Feb}_1+\mathrm{Dec}_2+2\ \mathrm{Jan}_2+\mathrm{Feb}_2)/12] \tag{15.5}$$

Each individual monthly result has the same probable error ρ_0, according to our assumption (a); according to (15.3), with $n=5$ for the Min_1-groups, and $n=3$ for the Min_2-groups (see Table 1), the group-averages have probable errors $\rho_0/\sqrt{5}$ and $\rho_0/\sqrt{3}$, respectively. Therefore, (15.2) gives for the square of the probable error of (15.5)

$$\begin{aligned}&\rho^2{}_0\times\{[4\times(1/5)+64\times(1/5)+4\times(1/5)+(1/3)+4\times(1/3)+(1/3)]/144\}\\&=\rho^2{}_0\times[(82/5)/144]=\rho^2{}_0/2.96^2\end{aligned} \tag{15.6}$$

For this value, we had the estimate $(0.833\times 7.4)^2$; therefore, $\rho^2{}_0=(2.96\times 0.833\times 7.4)^2=18.2^2$. Other differences between smoothed and original values yield further estimates for $\rho^2{}_0$, and from the average $\rho^2{}_0$ for several such determinations, the six values for ρ_0 in Table 11 are obtained.

TABLE 11—*Probable error-radii ρ_0 for lunar semimonthly waves in Huancayo H computed from individual months (unit, microgauss$=0.1\gamma$)*

Group	November to February	Equinoxes	May to August
Sunspot-minimum	136	112	69
Sunspot-maximum	166	117	67

These estimates for ρ_0 are likely to exceed the correct values by a few per cent because the differences between the original and the smoothed values will contain a systematic part while our calculation considered these differences as due only to irregular scattering. This keeps us on the safe side if we judge the reliability of the results by the probable error-radii ρ given in Table 12, which are deduced from the values ρ_0 in Table 11 by applying (15.2) and (15.3). These radii have

TABLE 12—*Probable-error radii for the average lunar semidiurnal waves in Tables 10-A to 10-D*

Group Original	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Dec.-solst.	Equi-nox	June-solst.
	Results in Table 10-*A*												Results in Table 10-*B*		
Min_1, in 0.1γ	61	61	50	50	31	31	31	31	50	50	61	61	30	25	15
Min_2, in 0.1γ	79	79	56	56	34	34	34	34	56	56	79	79	39	28	17
Max_3, in 0.1γ	83	83	58	58	33	33	33	33	58	58	83	83	42	29	17
Max_4, in 0.1γ	74	74	52	52	30	30	30	30	52	52	74	74	37	26	15
All, in 0.1γ	37	37	27	27	16	16	16	16	27	27	37	37	18	14	8
Smoothed	Results in Table 10-*C*												Results in Table 10-*D*		
"Min_1", in 0.1γ	29	29	25	22	16	14	14	16	22	25	29	29	24	19	12
"Min_2", in 0.1γ	26	25	21	18	13	12	12	13	18	21	25	26	22	16	10
"Max_3", in 0.1γ	28	27	21	19	13	12	12	13	19	21	27	28	23	16	9
"Max_4", in 0.1γ	35	33	26	23	16	14	14	16	23	26	33	35	28	20	11
All, in 0.1γ	21	20	16	14	10	9	9	10	14	16	20	21	18	14	8

also been used to construct the probable-error circles in Figure 9. That the probable errors ρ for January and December, February and November, etc., appear equal in Table 12 is, of course, a consequence of our restriction of ρ_0 to six values.

The physical significance of Table 11 will be discussed in § 15 (*b*).

(*d*) The ratio of the amplitude c_A to the probable error-radius ρ is an index for the "reliability" of the wave determination. These ratios are of the following order:

For the monthly means, four original sunspot-groups (Table 10-*A*) $c_A/\rho = 3$ to 4 for November to March, but as low as 1 in June, Max_3; for the smoothed monthly means, four sunspot-groups (Table 10-*C*) c_A/ρ lies between about 7 for December, January, and February, and 4 for June.

For the total monthly means, (row marked All), c_A/ρ lies between 3 and 6 for the original results (Table 10-*A*), and between 6 and 10 for the smoothed values (Table 10-*C*).

For seasonal averages, four sunspot-groups, original results (Table 10-*B*), c_A/ρ lies between 4 and 6; for smoothed results (Table 10-*D*), between 5 and 9.

For total seasonal averages, finally, the ratios c_A/ρ are as high as 11 for the December-solstice, 9 for the equinoxes, and 8 for the June-solstice.

(*e*) We now consider some consequences of our assumption (γ), that the cloud of points is circular.

In general, if ρ_2 is the probable error-radius for a circular cloud of points, the probable error ρ_1 for the one-dimensional distribution of the projections of the points on one direction is only

$$\rho_1 = 0.573\rho_2 \tag{15.7}$$

This follows, for normal distributions, from the facts, that the standard deviation of the one-dimensional projections is equal to the two-dimensional standard deviation of the circular cloud divided by $\sqrt{2}$, and that the factors by which the standard deviations must be multiplied

to obtain the probable errors are 0.8396 for ρ_2 and 0.6745 for ρ_1. This gives the factor $(\rho_1/\rho_2)=[0.6745/(0.8326\times\sqrt{2})]=0.573$, that is, (15.7).

With (15.7), provided that the error-radius ρ is small compared with the amplitude c_A, the probable error in the phase-angle α_A can be estimated as 0.573 (ρ/c_A) in angular measure; for instance, 3°.0 for the total average wave in the December-solstice. With (15.2), we can further decide whether some of the changes in the phase-angle α_A in Table 10-*B* are real or accidental, and find that the seasonal increase of α_A from January to June is doubtlessly systematic, while the slight changes in α_A with the sunspot-cycle cannot be regarded as statistically significant.

(*f*) We may, therefore, regard the average phase-angle α_A as a constant for each month or season, independent of the sunspot-cycle, and we can use (15.7) also to estimate the probable errors in the changes of the amplitudes c_A with the sunspot-number. The probable errors of the amplitudes are pictured as vertical bars in Figure 10, which represent

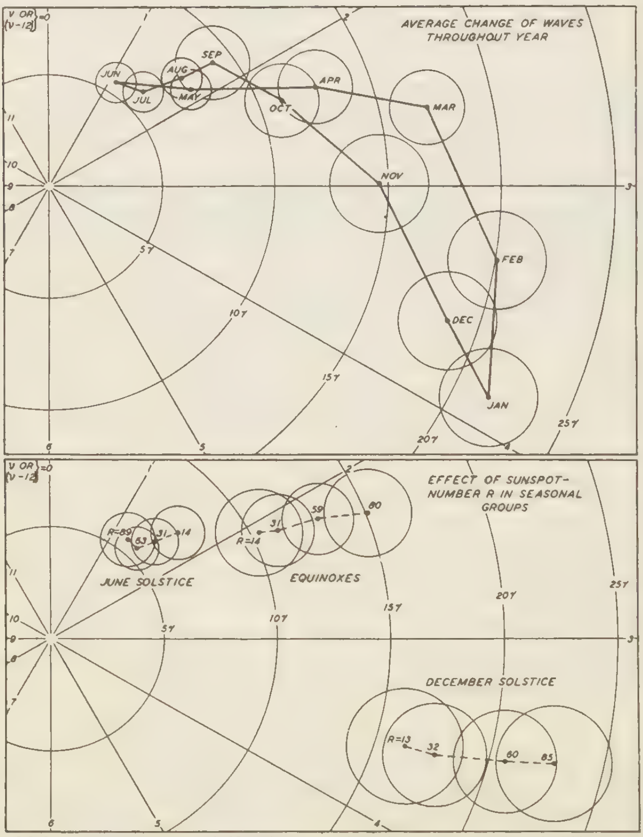


FIG. 9—HARMONIC DIALS, LUNAR SEMIMONTHLY SINE-WAVES IN DAILY RANGES A OF HORIZONTAL INTENSITY AT HUANCAYO, 1922-39 [AVERAGES WITH PROBABLE-ERROR CIRCLES]

the (smoothed) amplitudes in Table 10-*C* as functions of the average A_S. The significance of the increase of c_A with the sunspot-number can be judged from the following values which show the algebraic increase of c_A for typical values in Tables 10-*B* and 10-*C*, followed by $\pm$ the probable (one-dimensional) error of this increase (unit 0.1γ):

December-solstice:	$(\text{Max}_4 - \text{Min}_1) = (251-154) = +97 \pm 27$
Equinoxes:	$(\text{Max}_4 - \text{Min}_1) = (164-106) = +58 \pm 21$
June-solstice:	$(\text{Max}_4 - \text{Min}_1) = (58-82) = -24 \pm 12$
"January":	$(\text{"Max}_4\text{"} - \text{"Min}_1\text{"}) = (272-170) = +102 \pm 26$
"June":	$(\text{"Max}_4\text{"} - \text{"Min}_1\text{"}) = (55-65) = -10 \pm 11$

These values, and Figure 10—in which the vertical bars drawn for "Min_1" and "Max_4" indicate the limits within which the true value of c_A can be expected to fall with the probability one-half—show that the increases of c_A with the sunspot-cycle in the six months October to March are significant, because they are three to four times as large as their probable errors. The increase of c_A is most conspicuous for the December-solstice when the increase $(\text{Max}_4 - \text{Min}_1) = (251-154)\gamma = +97\gamma$, for an increase of R from 9 to 93, reaches half of $c_A \doteq 195\gamma$ for the total average wave for that season. As to the computed decrease of

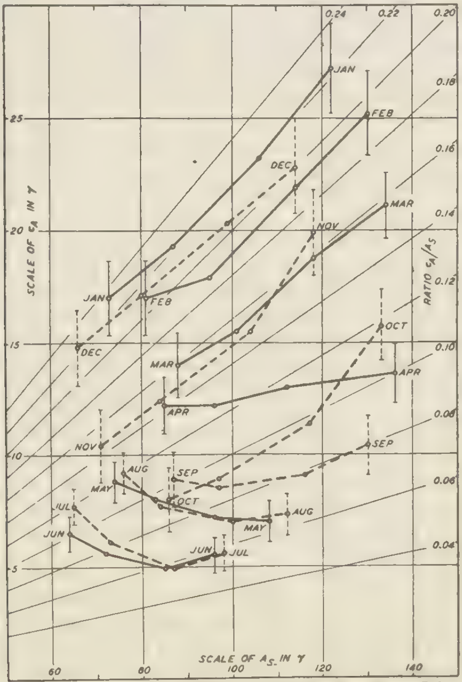


FIG. 10—DAILY RANGES, HORIZONTAL FORCE, HUANCAYO MAGNETIC OBSERVATORY; AVERAGES A_S, AND AMPLITUDES c_A OF LUNAR SEMI-MONTHLY SINE-WAVES FOR FOUR SUNSPOT-GROUPS (VERTICAL BARS GIVE PROBABLE ERRORS OF c_A)

c_A from sunspot-minimum to sunspot-maximum in the months May to August, it appears less reliable; but it can be said that an increase in the June solstice analogous to that for the December-solstice [by $(63/2) = 31\gamma$] is definitely excluded by the observations.

§ 16. *Discussion of the semimonthly waves*

The facts in Tables 10 to 12, illustrated in Figures 7 to 10, show the following main features of L in Huancayo H on days with $C < 1.2$ between 9^h to 14^h:

(*a*) *Magnitude of* L *and change with season*—In absolute units (Tables 10-A and 10-C) as well as relative to the average range A_S, the amplitude c_A reaches its highest value in January (more exactly around January 20, about a month after the date of the December-solstice), and its lowest value in the second half of June. Figure 10 illustrates, for the doubly smoothed results of Table 10-C, how c_A and A_S in the first half of the year compare with those in the second half. Symmetrical to July 1, June and July form a pair, also May and August, but c_A in September, and even partly in October, is definitely lower than in April, and c_A in October is lower than in March, so that c_A, for the same A_S, for November becomes equal to c_A in March. In other words, c_A decreases in the three months from March to June by about the same amount as c_A increases in the five months June to November.

The unsmoothed values for January give the highest ratio of (c_A/A_S), namely $(24.4\gamma/100.6\gamma) = 0.242$. This means that A, within a quarter month, from the maximum to the minimum of the semimonthly wave, changes in the ratio

$$[(A_S - c_A)/(A_S + c_A)] = [(1 - 0.242)/(1 + 0.242)] = 100/184 \qquad (16.1)$$

For June, with $(c_A/A_S) = (5.6\gamma/75.2\gamma) = 0.074$, this ratio becomes much smaller

$$[(1 - 0.074)/(1 + 0.074)] = 100/116 \qquad (16.2)$$

The lowest values (c_A/A_S), about 0.057, in Table 10-E are those for "Max_3" and "Max_4" for "June" and "July," which give for the ratio of the lowest to the highest A within a quarter-month (100/112).

The remarkable seasonal shift in the phase-angle α_A is best seen in Figure 9, which pictures the smoothed results of Tables 10-C and 10-D; the unsmoothed phase-angle $\alpha_A = 315°$ for January (which has only the probable error 5° because of the large c_A) would even place the maximum of the wave in January as late as $\nu_{max} = 4.5$ hours, against $\nu_{max} = 1.1$ hours in the smoothed "June". The whole change of phase-angle in the course of the year is therefore 103° in α_A, or 3.4 hours in ν_{max}, more than one quarter of the period of the semimonthly wave. With respect to new Moon the maximum of the semimonthly wave occurs latest when the amplitude c_A is greatest.

Figure 7 shows best that the change of c_A in the course of the year is not parallel to that of A_S, which has an annual variation with two maxima near the equinoxes and two minima near the solstices. The seasonal change of L (indicated by that of c_A) is more pronounced than that of S (indicated by that of A_S); this result conforms with previous experience.

(*b*) *The probable-error circles*—The elementary probable errors ρ_0

(Table 11) vary, in the course of the year, more like c_A than like A_S. This is shown in the following three lines, which express ρ_0, c_A, and A_S in such arbitrary units that the average for the three seasons is 100 for each parameter.

Parameter	December-solstice	Equi-noxes	June-solstice
Probable error-radius ρ_0	136	103	61
Amplitude c_A	152	98	49
Range A_S	98	116	86

This result is of interest. If, namely, ρ_0 were mainly caused by a day-to-day variability of S, it would mean that this S-variability should be less than half as big in June as in December—an inference made untenable by a direct test [§ 19 (*c*) VI]. An alternative possibility is that the day-to-day variability of the two daily variations, expressed as multiples of their respective ranges (say, A_S for S, and $2c_A$ for L) is so much greater for L than for S, that ρ_0 is governed more by the variability of L than by that of S, and the decrease of c_A from December to June is reflected in a decrease of ρ_0. This latter assumption seems consistent with occurrence of the "big-L-days" and the discussions in §§ 4-7, and will be considered again in § 19 (*c*) VII.

There is yet another aspect. It had been thought that L could be studied most successfully in those geomagnetic observations in which it is pronounced. This led to concentrating attention on the three months December, January, and February. The ratio (ρ_0/c_A), which is a good expression for the relative reliability of the wave computed from a single month, is then about $(15.1\gamma/22.7\gamma) = 0.66$. But for the equinoctial months, this ratio is only slightly higher, namely, about $(11.45\gamma/12.8\gamma) = 0.89$. Because of (15.3) the number of equinoctial months required for the same relative reliability of the semimonthly wave is therefore only $(0.89/0.66)^2 = 1.82$ times the number of months December, January, and February. Or, for the same number of months, and compared with months around January, the relative probable error-radius, ρ/c_A, will be $(0.89/0.66) = 1.35$ times bigger for equinoctial months and $(1.08/0.66) = 1.64$ times bigger for months May to August. The statistical value of months around June for studies of L in H at Huancayo is therefore not so much inferior to that of months around January as the decrease of c_A would indicate because this decrease in c_A is partly counterbalanced by a parallel decrease in ρ_0.

(*c*) *Change with the sunspot-cycle*—As shown in § 15 (*e*) and (*f*), only the amplitudes c_A, not the phases α_A, change significantly with the sunspot-number R. Figure 10 shows that, in the six months October to March, when c_A is large, it increases with R just like A_S. From Table 10-*C*, averages for c_A were formed for the five months "November" to "March"; they are given here with corresponding averages for R and A_S.

Sunspot-group	R	A_S	c_A	(c_A/A_S)
"Min_1"	13	76γ	14.6γ	0.192
"Min_2"	32	89γ	16.4γ	0.184
"Min_3"	60	108γ	19.9γ	0.184
"Min_4"	83	124γ	23.2γ	0.187
All	48.5	99.9γ	18.6γ	0.186

The small change of the ratio (c_A/A_S) means that effects of S and L on A, around January, keep nearly the same ratio in their increase with R; this will be further discussed in Part II.

The months of May to August show a decrease of c_A with R, as shown in the following data for the June solstice (from Table 10-B)

Sunspot-group	R	A_S	c_A	(c_A/A_S)
"Min$_1$"	14	68γ	7.4γ	0.109
"Max$_4$"	89	100γ	5.6γ	0.056

As we saw in § 15 (f), this decrease of c_A is perhaps not quite reliable, although an increase of c_A of the same order as in January is ruled out by the probable errors. So, while S increases with R in the June solstice (although not quite as much as around January), L seems rather to decrease.

§ 17. *Semimonthly waves on disturbed days*

The effect of magnetic activity on L was tested in a significant case, namely, for the months December, January, and February (when L is largest) at sunspot-maximum (when disturbances are most intense). Just as described in § 14, the average ranges and the lunar semimonthly sine-waves were computed for the 136 disturbed days ($C \geqq 1.2$) and compared with those for the 608 undisturbed days ($C < 1.2$) in the same months.

Undisturbed days	$A = 119.5\gamma + 24.4\gamma \sin (2\nu + 340°)$
Disturbed days	$A = 112.0\gamma + 21.8\gamma \sin (2\nu + 299°)$

The reduction of the average A from 119.5 to 112.0γ is an effect of the solar disturbance daily variation S_D, as discussed in § 13. The effect of magnetic activity on the lunar semimonthly wave appears rather small. The vectorial difference between the two waves, that is, the distance between the two points representing the waves in a harmonic dial, is 16.4γ; its probable error would be 8γ under the assumption that $\rho_0 = 16.6\gamma$ per month for the undisturbed days (as in Table 12), and $\rho_0 = 16.6\sqrt{(608/136)} = 35\gamma$ per month for the disturbed days. But this estimate of ρ_0 for the disturbed days is certainly too small, because the irregular fluctuations of A on disturbed days (values between -68γ and $+235\gamma$) are greater than those on undisturbed days. Therefore, in discussing the result, the similarity of the two lunar waves seems more significant than their somewhat uncertain difference. And if L in H at Huancayo changes so little with such a large increase in magnetic activity, it seems justified to consider all days with $C < 1.2$ without further distinction, as is done in this paper.

§ 18. *The corrected ranges A_S*

Since each daily variation is a superposition (S+L), each daily range A can be regarded as an algebraic sum of two ranges, of S and L, or

$$A = A_S + A_L \tag{18.1}$$

where A_S and A_L are both taken with their appropriate sign resulting in (12.1).

In order to arrive at A_S, we must eliminate A_L. This is done by assuming, for each calendar month, a lunar semimonthly sine-wave $c_A \sin(2\nu+\alpha_A)$ as follows: The phase-angles α_A are those given in the last line of Table 10-A, independent of the sunspot-cycle. The amplitude c_A is assumed to be a function of the average amplitude A for the month; this function is given, for each month separately, in Figure 10. The actual computation runs as in the following example, for January 1923: The monthly averages A for the months December 1922, January and February 1923, are 57, 73, and 82γ, which gives for the smoothed average A for "January 1923" the value 71γ. From Figure 10 we read, by a slight extrapolation, the value 16.8γ for c_A. In order to eliminate the effect of smoothing, we multiply this value by the ratio $(24.4\gamma/21.9\gamma)$ of the original to the smoothed monthly means for January, as given in Tables 10-A and 10-C, and obtain the round value of 19γ for c_A. Therefore, the daily values A_L of the wave $19\gamma \sin(2\nu+315°)$ are subtracted from the daily values of A in January 1923; the result is a range which is freed from the average influence A_L of L. This corrected daily range is called A_S and is assumed to express the intensity of S.

The monthly averages of A and A_S do not differ systematically, but in each individual calendar month the difference (A_S-A) may differ from zero because the calendar month is longer than the lunar month, and because the disturbed days are omitted. Thus, on the average, for January 1937, $(A_S-A)=(153-158)=-5\gamma$. But these individual monthly differences (A_S-A) are generally smaller, as shown by their standard deviations from their average value zero, namely, for the months December, January, and February, (when L is large) 2.4γ, and for the months May to July (when L is small) 0.6γ.

§ 19. *Influence of L on the variability of A and A_S*

The cases of abnormally large L discussed in §§ 4 to 7 make it probable that the corrected ranges A_S may show residual lunar influences, because the correction described in § 18 eliminates, so to say, only the normal L. Since A_S is proposed as a measure for the intensity of S, we will discuss how much L still affects A_S; furthermore, the variability of L itself is of interest. The following discussion is restricted to typical cases and is not intended to exhaust the rather intricate problem of the joint variability of S and L.

(*a*) *A curious mistake and its lesson*—The following way of studying the variability of L suggests itself: In the average for December, January, and February, at sunspot-minimum, the average A and the semimonthly wave in A is given by

$$A=(A_S+A_L)=[71\gamma+18\gamma \sin(2\nu+341°)] \tag{19.1}$$

The maximum of the semimonthly wave occurs at $\nu=(109°/2)$, or approximately $\nu=4$ hours. This means that, for all days with ν or $(\nu-12)=4$ and 10 hours, at the maximum and minimum of the wave, the average A is 89γ and 53γ, respectively. If, now, A_L on these days varies much about its mean value 18γ, A on these days will be occasionally much higher or much lower and will fluctuate more than for ages 1 and 7 hours, when A_L is small. A seemingly unbiased test of this consideration was made by selecting, in each calendar month, the

three days with the three highest ranges A, and the three days with the three lowest ranges A; from all these ranges (144 in number) for the 24 calendar months the lunar semimonthly sine-wave was computed in the usual manner (§ 14), and gave

$$73\gamma+41\gamma \sin (2\nu+339°) \qquad (19.2)$$

While the phase-angle $a_A=339°$ is practically equal to that given in (19.1) as derived from all days, the amplitude $c_A=41\gamma$ is more than twice as large as the ordinary amplitude $c_A=18\gamma$ given there; according to (19.2) A varies with the Moon's age, on these selected days, between $(73-41)\gamma$ and $(73+41)\gamma$, or in the astonishing ratio 1.0 to 3.6.

At first sight one might be tempted to draw the conclusion that the intensity of L is more than doubled on these six selected days per month with the three highest and the three lowest ranges A, thus confirming our suspicion that the variability of L is large. This would, however, be a curious mistake which deserves mention as a standard example of erroneous interpretation of biased sampling, of the same nature as a mistake recognized earlier [16]. There is, namely, another, quite different, interpretation which, although likewise schematic, is nearer the truth: We may assume that in the equation $A=A_S+A_L$, day by day, A_L depends rigidly on ν as expressed in (19.1), without any deviation, while the whole irregular variability of A is due to A_S which fluctuates around its average value 71γ according to a frequency-distribution that is independent of ν. The ranges A, for days with ν or $(\nu-12)=4$ hours would then fluctuate around their average value 89γ, and the ranges A for days with ν or $(\nu-12)=10$ hours would fluctuate around their average value 53γ. The three highest ranges per month would preferably occur on days with ν or $(\nu-12)$ around 4 hours, and their average value, say, A_{max}, would be higher than 89γ by an amount depending on the standard deviation of A_S and the relative number of days selected; likewise, the three lowest ranges per month would preferably occur on days with ν or $(\nu-12)$ around 10 hours, and their average value, say A_{min}, would be lower than 53γ.

This is confirmed by the following somewhat condensed data of our example which comprised 24 calendar months:

Three ranges per month	Number of days with ν or $(\nu-12)$ hours 0, 1, 2	3, 4, 5	6, 7, 8	9, 10, 11	Total	Average A
With highest A	16	42	11	3	72	110γ
With lowest A	16	6	14	36	72	36γ

Furthermore, the deviations $\triangle A$ of the daily ranges A from the average A_S for each calendar month were formed; for instance, $A=60\gamma$ for the day January 1, 1923, the average A_S for the month of January 1923, is 75γ, therefore $\triangle A=-15\gamma$ for that day. These values have been plotted at the left in Figure 11, distributed according to ν or $(\nu-12)$ hours.

The average semimonthly sine-waves, with the parameters $(c_A; a_A)$, for the months in sunspot-minimum, are formed from these daily departures $\triangle A$ as $(18.2\gamma; 329°)$ for December, $(20.8\gamma; 320°)$ for January, $(21.3\gamma; 355°)$ for February; in order to eliminate the seasonal change in phase-angle, the days with ν for February were combined in the graph

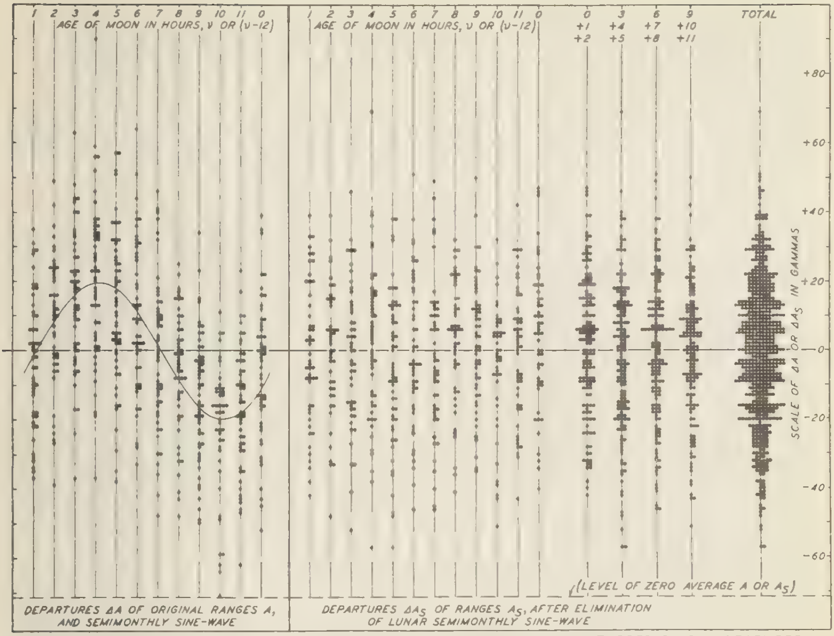


FIG. 11—DAILY RANGES IN HORIZONTAL INTENSITY AT HUANCAYO ON 607 UNDISTURBED DAYS IN DECEMBER, JANUARY, AND FEBRUARY, AT SUNSPOT-MINIMUM, IN DEPARTURES FROM THEIR RESPECTIVE MEANS FOR CALENDAR MONTHS, DISTRIBUTED ACCORDING TO THE MOON'S AGE

with those for $(\nu+1)$ hours for December and January, so that the average wave for the three months gets a somewhat larger amplitude than that given in (19.1) and becomes

$$20.1\gamma \sin (2\nu+325°) \tag{19.3}$$

The features discussed above appear distinctly in this diagram; for clearness the values ν begin in Figure 11 with 1 (for December and January, or 0 for February), because the sine-wave (19.3) goes through zero for $\nu=17°.5=1.2$ hours.

(*b*) *Residual lunar influences in the corrected ranges* A_S —Figure 11 shows, at the right, the deviations $\triangle A_S$ of the corrected ranges A_S from the average A_S for each calendar month; for January 1, 1923, $A_S=77\gamma$, $\triangle A_S=+2\gamma$. Each dot for a value $\triangle A_S$ at the right in Figure 11 is obtained from a dot, for the value $\triangle A$ for that day at the left by subtracting A_L as in § 18. The twelve frequency-distributions of $\triangle A_S$ for each value of ν or $(\nu-12)$ are combined into four distributions for values of ν centered at 1, 4 (near the maximum of the wave), 7, and 10 hours (near the minimum of the wave), and finally superposed to give the total distribution of $\triangle A_S$ for all 607 days.

With the three (algebraically) highest and lowest values of $\triangle A_S$ per month, the lunar semimonthly wave was found as $3.3\gamma \sin (2\nu+76°)$, with a probable error that can be estimated to exceed the amplitude

3.3γ. Therefore, the influence of L on the highest and lowest values of $\triangle A_S$ seems so small that it cannot be detected with certainty, at least not in this way; evidence speaking for a slight residual influence will be discussed in the next section (*c*), and then there are, of course, those lunar influences which originate in tidal terms other than M_2 (to be discussed in Part II), and those features of L in the hours after 14^h which are so conspicuous on the "big-L-days," but are not expressed in the range A.

(*c*) *The joint variability of* S *and* L—The right half of Figure 11 gives the impression that the dots scatter more for the ages around $\nu=4$ hours than for those around $\nu=10$ hours. This is confirmed by the standard deviations σ ($\triangle A_S$) for $\triangle A_S$, namely,

for ν or $(\nu-12)$, in hours, =	0, 1, 2	3, 4, 5	6, 7, 8	9, 10, 11	All
$\sigma\ (\triangle A_S)=$	19.3γ	22.0γ	20.2γ	18.3γ	20.0γ

The excess $(22.0-18.3)=3.7\gamma$ is small, but significant; since, namely, the standard deviation of σ is $(\sigma/\sqrt{2n})$, where n $(=153)$ is the number of independent observations, the probable error of 3.7γ can be estimated as 1.1γ leaving a margin even if n were effectively reduced by quasi-persistence in $\triangle A_S$. This result throws some light on the variability of $A=A_S+A_L$, or, if we call A_0 the monthly average of A or A_S, on the day-to-day variability of $\triangle A=(A-A_0)=(\triangle A_S+A_L)$. Consider a few ideal cases:

(I) If A_L never deviates from exactly $c_A \sin(2\nu+\alpha_A)$, its variance is $\sigma^2(A_L)=c^2{}_A/2$, and

$$\sigma^2(A)=\sigma^2(A_S)+c^2{}_A/2 \tag{19.4}$$

In our example, with $\sigma\ (A_S)=20.0\gamma$, $\bar{c}_A=20.1\gamma$ [after (19.3)], this gives $\sigma\ (A_L)=14.1\gamma$, and $\sigma\ (A)=24.5\gamma$. This consequence is purely mathematical, due to the least-square method of determining c_A, and a test by computing $\sigma\ (A)$ directly would be nothing more than a check on the harmonic analysis, but not on the hypothesis.

(II) Suppose, next, that $A_L=c_\nu \sin(2\nu+\alpha_A)$ is only an approximation to the actual lunar range, which may be $(A_L+\delta_L)$. Then, the solar range is $[A-(A_L+\delta_L)]$, and its deviation from the average A_0 is $\delta S=[A-A_0-(A_L+\delta_L)]$. In other words,

$$A=(A_0+A_L+\delta_S+\delta_L) \qquad \triangle A_S=(A-A_L-A_0)=(\delta_S+\delta_L) \tag{19.5}$$

(III) If δ_S and δ_L were statistically independent, and if the standard deviations $\sigma\ (\delta_S)$ and $\sigma\ (\delta_L)$ were independent of ν, (19.5) would give

$$\sigma^2(\triangle A_S)=\sigma^2(\delta_S)+\sigma^2(\delta_L) \tag{19.6}$$

likewise independent of ν; this contradicts the observation, as we have seen above, since $\sigma\ (\triangle A_S)$ is 22.0γ for $\nu=4$ hours, and only 18.3γ for $\nu=10$ hours.

(IV) If we keep the assumption that δ_S and δ_L are independent, and that $\sigma\ (\delta_S)$ does not depend on ν, then the decrease, from $\nu=4$ to $\nu=10$, of $\sigma^2(\triangle A_S)$ from $484\gamma^2$ to $335\gamma^2$ would be wholly due to a decrease of $\sigma^2(\delta_L)$. Even if $\sigma\ (\delta_L)$ were zero for $\nu=10$ hours, this would give, for $\nu=4$ hours $\sigma^2(\delta_L)=149\gamma^2$, and $\sigma\ (\delta_L)=12.2\gamma$, making $\sigma\ (\delta_L)$ nearly equal to $\sigma\ (A_L)=14.1\gamma$. This estimate for $\sigma\ (\delta_L)$ appears rather high, because it reaches 61 per cent of c_A.

(V) We therefore test the hypothesis that S and L vary proportionally, an assumption which would be natural in the dynamo-theory, if the currents for S and L flow in the same ionospheric layer. Suppose

$$\delta_L/A_L = f\,(\delta_S/A_0) = \epsilon \tag{19.7}$$

with a constant ratio f. Then

$$\triangle A_S = (\delta_S + \delta_L) = \epsilon[(A_0/f) + A_L] \tag{19.8}$$

$$\sigma\,(\triangle A_S) = \sigma\,(\epsilon)[(A_0/f) + A_L] \tag{19.9}$$

If $\sigma\,(\epsilon)$ is supposed independent of ν, the ratio of our values $\sigma\,(\triangle A_S)$ for $\nu = 4$ and 10 would give $(22.0/18.3) = \{[(71/f)+20]/([71/f)-20]\}$, or about $f = 1/3$. This is certainly too small, since, with $\sigma\,(\delta_S/A_0) = 20.0/71.0 = 0.28$, (19.7) would give $\sigma\,(\delta_L/A_L)$ only 0.09, obviously contradicting the existence of the "big-L-days" which, in any case, would suggest values of f exceeding unity. Or, put differently: If the variability of (S+L) should vary with ν proportional to $(A_0 + A_L)$, we would expect the standard deviations $\sigma\,(\triangle A_S)$ for $\nu = 4$ and 10 hours to stand in the ratio $[(71+20)/(71-20)] = (1/0.56)$; the values for $\sigma\,(\triangle A_S)$ for $\nu = 4$ and 10 actually found from the observations show, in fact, a difference in the right direction, but the ratio is only $(22.0/18.3) = (1/0.83)$. This points to the conclusion that to a considerable extent S and L do not vary in unison, but independently. The actual conditions will be a compromise between the extreme hypotheses (IV) and (V).

(VI) We compare the following values for sunspot-minimum. For June, average $A_0 = 60\gamma$, $c_A = 4.9\gamma$, $\sigma\,(\triangle A) = 15.6\gamma$, $\sigma\,(\triangle A_S) = 15.2\gamma$; for the months December to February, average $A_0 = 71\gamma$, $c_A = 20.1\gamma$, $\sigma\,(\triangle A) = 25.4\gamma$, $\sigma\,(\triangle A_S) = 20.0\gamma$.

The relative scattering of the corrected ranges, $\sigma\,(\triangle A_S)/A_0$ is 0.25 for June, 0.28 for December to February, not much different, but consistent with the view that the smaller average intensity of L in June, as indicated by c_A, is accompanied by a smaller (absolute) variability of L, expressed in a reduction of $\sigma\,(\triangle A_S)/A_0$.

(VII) The standard deviation of $\triangle A_S$, at sunspot-minimum, has been found above as $\sigma = 20.0\gamma$ in the months December to February, and $\sigma = 15.2\gamma$ in June. In Table 11 (§ 15), the probable errors of the lunar semimonthly wave from single months were found as $\rho = 13.6\gamma$ and 6.9γ, respectively. In the case of random scattering [15], harmonic analysis of sets of n equidistant ordinates with standard deviation σ yields a root-mean-square sine-wave amplitude $(2\sigma/\sqrt{n})$, for any frequency, or a cloud of points with probable error-radius $\rho = (0.833 \times 2\sigma/\sqrt{n})$. Inserting our values for σ and ρ, we compute $n = 6.0$ around January, $n = 13.4$ for June, for the "equivalent number of random daily values per month," to be compared with the actual number of days used per month, about 25. This gives $25/n$—about 4 and 2—for the "equivalent number of repetitions" of daily values $\triangle A_S$, indicating the conservation tendency in A from day to day as expressed in semimonthly waves. This number is higher around January, when L is large, possibly because the variability of L is then also large and quasi-persistent.

(VIII) Of the 607 days pictured in Figure 11, not one has a range A_S double that of the normal range; in other words, $\triangle A_S$ never exceeds

A_0. While S thus never appears doubled, the "big-L-days" make it necessary to assume this for L.

(*d*) *Effect of the variability of* L *on the use of* A_S *for measuring* W—. The preceding discussion supplements the impression gained from the "big-L-days" that L varies, to a large extent, independently of S. That the day-to-day variability of L is greater than that of S—not in absolute units, but relative to the average variations L* and S*—appears in the "big-L-days" most clearly in the afternoon hours in which S is small. From 9^h to 14^h, when S is large, the irregular fluctuations of L add only little to those of S. Since these are the hours from which A is derived, it appears that the residual fluctuations of L do not seriously endanger the use of A_S as a measure for the intensity of S, even in those months when L is large. Especially, if A_S will be determined from a number of observatories [21], the residual influences of L on the combined average of the A_S will probably not exceed a few per cent of the standard deviation of this proposed day-to-day measure of solar wave-radiation W.

References

[1] S. Chapman and J. Bartels, Geomagnetism, 2 vols., xxviii+1049+77 pp., Oxford University Press, 1940. (The lunar magnetic variations are discussed in chapters 5, 8, 19, 20, and 23.)
[2] Terrestrial magnetism and electricity, edited by J. A. Fleming, (Phys cs of the Earth, vol. VIII), xii+794 pp., McGraw-Hill Book Company, New York and London, 1939.
[3] S. Chapman and J. C. P. Miller, Mon. Not. R. Astr. Soc., Geophys. Sup., **4**, 649-669 (1940).
[4] J. Bartels and H. F. Johnston, Trans. Amer. Geophys. Union 1940,273-287, 1940.
[5] J. Bartels and G. Fanselau, Geophysikalischer Mondalmanach, Zs. Geophysik, **13**, 311-328 (1937) [partly translated in Terr. Mag., **43**, 155-158 (1938)].
[6] J. Bartels and G. Fanselau, Geophysikalische Mondtafeln 1850-1975. Abh. Geophys. Inst. Potsdam No. 2, 44 pp. (1938).
[7] Ref. [1], p. 86f.
[8] A. T. Doodson, Proc. R. Soc., A, **100**, 305-329 (1921).
[9] J. Bartels, Gezeitenkraefte, in Handbuch der Geophysik, **1**, 309-339, Gebr. Borntraeger, Berlin (1932).
[10] Ref. [1], p. 679.
[11] Ref. [1], Chapter 8.
[12] J. Bartels, Beitr. Geophysik, **54**, 56-75 (1938).
[13] J. Bartels and H. F. Johnston, Terr. Mag., **44**, 455-469 (1939).
[14] Harmonic dial and clouds of point are described in [1], Chapter 16, or in J. Bartels, Terr. Mag., **37**, 291-302 (1932).
[15] Ref. [1], Chapter 16.
[16] Ref. [1], §8.18.
[17] Ad. Schmidt, Archiv des Erdmagnetismus, Heft 7; appeared as Berlin, Abh met. Inst., **9**, No. 1 [Veröff. No. 357] (1928).
[18] M. Bossolasco and J. Egedal, Terr. Mag., **42**, 123-126 (1937).
[19] J. Egedal, Terr. Mag., **42**, 179-181 (1937) and **43**, 89 (1938).
[20] W. J. Rooney, Terr. Mag., **43**, 107-118 (1938).
[21] J. Bartels, Solar radiation and geomagnetism, Terr. Mag., **45**, 339-343 (1940).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

GEOMAGNETIC THREE-HOUR-RANGE INDICES FOR THE YEARS 1938 AND 1939

By J. Bartels, N. H. Heck, and H. F. Johnston

Abstract—The paper gives three-hour-range indices K for seven observatories for July 1, 1938, to December 31, 1939 (Table 1), world-wide three-hour-range indices K_w for 1938 and 1939 (Table 2, which will be used most often), and, based on K_w, daily indices B (Table 3) and monthly frequencies and averages (Table 4). Section (1) contains all the information necessary for using these Tables in geophysical or ionospheric work.

Sections (2) to (5) show how the indices K are standardized by means of keys for transforming K into reduced indices K_r. The world-wide K_w is introduced as an average of the reduced indices K_r, in which the K_r from polar stations enter with higher weight than the K_r from equatorial stations. K_w is proposed as a measure of the intensity P of solar corpuscular radiation.

Note—Throughout this paper, a superior cross (×) denotes a half unit, thus, $0^\times = 0.5$, $1^\times = 1.5$, etc.

§ 1. *Description of the current tables and diagrams*

The three-hour-range index K expresses, by an integer between 0 and 9, the intensity of the magnetic disturbance at an observatory for each of the eight three-hour intervals of the Greenwich day, as described in our first paper,[1] to which the reader is referred for details; the present paper will, however, be self-contained in that the tables and their use will be explained.

Table 1—Original K-indices, for July, 1938, to December, 1939, for the seven observatories Si = Sitka (Alaska), Ni = Niemegk (Potsdam, Germany), Ch = Cheltenham (Maryland), Tu = Tucson (Arizona), SJ = San Juan (Puerto Rico), Hu = Huancayo (Peru), and Wa = Watheroo (Western Australia). The first of the eight indices given for each Greenwich day refers to the interval 00^h to 03^h GMT. The indices for January to June, 1938, were given on pages 434-439 of our first paper,[1] together with those for Ho = Honolulu.

In case of incomplete records, indices could easily be estimated from those given by the other observatories for the same intervals. There are again a few cases in which the range was clearly raised by the geomagnetic effect of a solar flare, that is, by a non-corpuscular solar influence; for these intervals, a "non-flare-K", or K', was also estimated [used for deriving K_r, see section (4)], as follows:

January 16, 1938, 00^h-03^h GMT: Ho $K=2$, $K'=0$; Wa $K=5$, $K'=1$. September 20, 1938, 15^h-18^h GMT: Ch $K=2$, $K'=1$; Tu $K=2$, $K'=1$; SJ $K=2$, $K'=1$; Ho $K=3$, $K'=0$; Hu $K=5$, $K'=2$; 18^h-21^h GMT: Hu $K=5$, $K'=0$. September 23, 1938, 15^h-18^h GMT: Hu $K=4$, $K'=2$. December 7, 1938, 18^h-21^h GMT: Si $K=1$, $K'=0$; Ch $K=4$, $K'=1$; Tu $K=5$, $K'=1$; SJ $K=3$, $K'=0$; Ho $K=2$, $K'=0$; Hu $K=2$, $K'=1$. August 29, 1939, 18^h-21^h GMT: Hu $K=2$, $K'=1$.

Table 2—World-wide indices K_w, and their daily sums, 1938-39, are given in Table 2. Eight indices are given for each Greenwich day, the first referring to the interval 00^h to 03^h GMT. K_w is given to half a unit; for economy in printing, half-units are indicated by crosses (×). The new Table supersedes the previous Tables for $2K_m$ for the first half of 1938.

[1]Terr. Mag., **44**, 411-454 (1939). Since February 1, 1940, the K-indices for Cheltenham are broadcast daily in the cosmic-data Ursigram (see Note in Terr. Mag., **45**, 112, 1940), and since April 1, 1940, the weekly "Cosmic-data" Bulletins issued by Science Service, Washington, D. C., contain the K-indices for seven American-operated observatories.

Table 1--Three-hour-range indices, K, July 1938 to December 1939

July 1938

	1	2	3	4	5	6	7	8
Si	3546 5234	3454 4222	1331 2110	2334 7455	4422 5221	3443 4221	1110 2212	2222 3110
Ni	2332 4324	3423 3210	0210 0110	1110 5555	4323 4231	2212 3421	1100 2221	2212 2210
Ch	2445 3335	3432 3321	0310 0210	1332 5457	5421 4233	3534 3320	1221 2233	2211 2220
Tu	3544 2334	3342 2222	1311 0122	2213 5466	5433 4242	2432 2221	1221 2212	1212 2110
SJ	3433 3224	2422 1200	0321 0111	1321 4466	4423 4243	3423 3321	1110 2212	2222 2221
Hu	2423 4423	2322 3310	1311 1110	1321 5555	4324 5332	2412 3320	0100 2321	1211 2220
Wa	2443 3423	2323 2210	0100 0000	2111 4335	4321 4210	2222 3110	2220 1001	2121 2000

	9	10	11	12	13	14	15	16
Si	2120 0133	4454 4343	3321 0011	2100 2111	1111 2224	5512 3233	2444 5566	4337 6343
Ni	2112 1244	4332 3654	4211 1111	1211 3211	1223 3344	5412 3232	1453 5566	5323 4353
Ch	2010 1244	5532 3344	3211 0022	2211 2222	2122 2345	5412 3244	2445 5567	5334 3353
Tu	2010 1245	4332 3554	2111 2122	2221 2222	2222 3236	4412 3233	1444 5656	5433 4333
SJ	2111 2234	4322 2353	2212 2232	1211 2322	1222 3335	3412 3243	3435 3445	4323 4244
Hu	1000 1342	4322 3553	2101 2230	1102 3321	1113 4445	3411 4331	1444 6664	4323 3453
Wa	2111 0233	4332 3242	3210 0000	2121 1101	1221 1123	4322 3222	2244 5665	4324 3232

	17	18	19	20	21	22	23	24
Si	3342 1021	0111 2222	3123 3122	2221 1223	3123 2121	0232 1211	2221 1122	3001 2122
Ni	1321 0110	0101 2311	4122 2121	1211 1322	2111 2211	1111 1321	1100 2323	2112 1212
Ch	2330 0001	0111 1313	3122 1212	2230 2323	2121 2212	0231 0111	1120 1123	1000 1022
Tu	2331 1011	0011 1232	3122 2112	2221 1223	2122 2212	0131 0211	2220 1112	2011 2012
SJ	2331 0010	0111 2111	3012 0111	1232 3212	1111 1111	0221 1120	1110 1222	1102 1112
Hu	1210 1110	0011 2321	3012 2221	0230 1320	1111 2211	0221 1430	1110 2421	1000 2222
Wa	1330 0000	0100 0100	2123 1100	1111 1112	2121 1111	0111 0110	1110 1212	1111 1211

	25	26	27	28	29	30	31	
Si	2100 0000	0011 2111	0210 0121	1100 0200	0112 3323	4788 5243	3202 0100	
Ni	2000 1000	0010 1110	0110 2101	0100 2210	0112 3233	3533 5344	3111 1010	
Ch	2000 0000	0000 0010	0210 1212	0000 0100	0122 2234	4665 4244	4101 0010	
Tu	2000 0010	0011 0001	0210 0112	0000 0110	0122 2234	3665 4244	4201 0000	
SJ	2100 0110	0000 1110	0210 1112	0001 1100	0122 2223	3454 4344	3201 1010	
Hu	2100 0120	0000 1100	0200 1221	0000 1310	0121 3332	3543 5453	3101 1100	
Wa	2100 0000	0010 2100	0210 1101	0000 0000	0121 2223	2554 4233	3111 0000	

August 1938

	1	2	3	4	5	6	7	8
Si	1224 4434	4731 2334	3310 0226	4597 6333	5542 5443	3344 3322	2442 3320	1221 2011
Ni	1133 3534	4522 3345	4210 0337	5554 4544	4532 5443	3322 1333	1211 4422	1112 1032
Ch	1233 2435	4622 2234	4320 0336	5566 3436	5532 3343	5321 0222	0440 2222	1222 0022
Tu	2243 3435	4633 2334	4320 0337	5565 4334	4542 2343	4322 1212	1441 2332	1222 1111
SJ	1142 2333	4522 0233	3220 0327	5444 2334	4432 1242	3311 0211	1331 2222	1222 1122
Hu	1132 3544	4431 3333	2210 1436	4443 4533	3432 3542	3311 2431	1322 4422	1121 2121
Wa	1142 2523	3432 1334	3120 0226	3554 4431	2321 3321	3221 1311	0221 1321	0122 1011

	9	10	11	12	13	14	15	16
Si	2020 2021	2433 2222	2357 7732	3332 2231	3320 1011	1000 2120	0001 0110	0000 0000
Ni	1000 3112	1333 3422	3343 4534	3323 3232	2321 2121	1101 2212	0010 0100	0001 0000
Ch	1000 2012	1322 2333	3436 5434	2332 2223	3430 1011	1100 2111	0000 0110	0000 0001
Tu	1000 2112	0332 2332	3446 5445	3333 2323	3441 2011	1101 3110	0000 1101	1110 0100
SJ	1101 2111	0322 2332	2436 2343	2333 2322	3411 2121	1101 2110	0000 0100	0010 0111
Hu	1000 3310	0323 4532	2325 5554	2324 4342	3331 3220	1101 4320	0000 1210	0010 0010
Wa	1110 2000	1322 2111	1246 6432	2333 2222	3331 1010	1100 2110	0000 0100	0000 0000

	17	18	19	20	21	22	23	24
Si	0012 3110	2000 0111	0002 1111	0001 0000	0000 3231	1200 3342	3337 4221	2001 2123
Ni	0001 3311	1100 1111	1100 1221	1110 0111	0011 3322	1211 5443	3335 5332	1022 3245
Ch	0010 0202	2000 0011	0100 0021	0011 0011	0111 2221	1300 5464	4335 5232	1011 2244
Tu	0011 2111	2001 0011	0110 0112	0100 0011	0100 3231	1200 5454	4445 4232	2122 2134
SJ	0011 1100	1001 0011	0101 0111	0001 1111	0100 2321	2200 2353	3335 4231	2011 2234
Hu	0010 2410	2000 1211	1110 1210	0110 1211	0101 3330	1100 6662	3334 6432	1112 4334
Wa	0010 2100	1000 0010	0010 0100	0000 0001	0000 1331	1100 4322	3345 4221	1111 2132

	25	26	27	28	29	30	31	
Si	3100 0220	0000 0010	0002 0010	1001 0321	2232 2132	3413 2121	2323 3000	
Ni	4320 1231	1110 1022	1101 1112	0101 1333	2232 1142	3422 3121	2212 2110	
Ch	4210 1221	0110 0021	0011 0000	1100 0333	3323 0132	3412 2232	2221 0000	
Tu	3210 0121	1100 0021	1011 0010	1000 0243	2333 1133	3413 2121	2321 1100	
SJ	2210 0221	0110 0021	0010 0110	1000 0343	3333 0032	2411 0111	1320 0100	
Hu	3100 1310	0100 1210	0001 1210	1000 2542	2232 2342	2402 4310	1221 2210	
Wa	2110 0021	0110 0001	0000 0100	0100 1233	2232 0031	2211 1120	1112 2000	

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

September 1938

	1	2	3	4	5	6	7	8
Si	0131 1111	0020 0001	2235 4211	1022 2212	1123 3310	0000 0002	1231 1321	2212 2231
Ni	2111 0221	1101 1112	2222 2322	1112 2223	4312 4421	0001 1112	2112 1420	2111 2221
Ch	0220 0122	0011 0013	2133 1223	0012 1223	3312 3310	0000 1013	2311 1331	2222 1232
Tu	1220 0112	0011 0112	2224 2213	0012 2323	2223 4210	0101 1013	2331 1231	2332 1222
SJ	0110 0222	1101 0112	2234 1222	0002 1223	2322 3200	0101 1013	2321 1231	2222 1232
Hu	0110 2321	0011 2222	1224 3122	0000 4433	2202 5520	0001 2322	1212 2541	2111 3441
Wa	0110 0111	0101 0102	2212 2311	0001 1212	1112 3200	0100 1002	2211 1210	2111 2111

	9	10	11	12	13	14	15	16
Si	0023 3220	1334 4121	1104 3131	2132 3121	2422 0243	4624 5755	6788 8743	3220 2233
Ni	0122 2332	2122 3222	2212 1223	2221 2233	1412 1256	5611 3555	6544 6564	3311 2223
Ch	0122 2232	1222 2211	3302 2232	3431 1123	1421 1155	4432 3555	6666 6554	5321 1123
Tu	0132 2232	1223 2212	2202 3222	2231 2322	2422 1154	5522 4634	6676 5453	5332 2123
SJ	1121 2342	1222 2111	2202 2132	1222 1022	1421 1155	4523 3644	5455 6445	4322 2132
Hu	0112 3441	1211 2430	2201 3432	1020 3331	2311 2465	4421 4654	4344 5553	3212 2322
Wa	0121 3221	1113 3211	2101 2221	1111 2221	1322 1244	4411 4444	3457 7554	3212 1132

	17	18	19	20	21	22	23	24
Si	2532 3310	1031 1101	1110 0121	2032 1110	0021 1131	2344 2210	1332 1120	0000 1011
Ni	2311 3210	1112 2203	1011 0112	2122 2110	0122 1134	2223 3210	2432 1112	1001 1113
Ch	3411 2120	2121 1101	1110 0022	2221 2210	0111 0143	3343 2221	2431 1112	0000 0111
Tu	2521 1121	2131 1001	1110 0022	2131 2210	0121 0134	4344 2122	2432 1111	1000 0011
SJ	3321 1121	2221 1210	1110 1212	2121 2200	0121 1033	3333 1222	2331 0111	0100 0110
Hu	1311 4310	1021 2311	0111 1321	2021 3550	1111 3332	2333 3421	2332 2421	1000 1221
Wa	2211 3210	1111 1101	1110 0101	2131 2100	1121 1332	2223 1110	2331 1101	0100 1101

	25	26	27	28	29	30
Si	0002 3111	3257 7544	3444 5415	7743 4331	1256 5311	1223 4354
Ni	1111 1222	3254 3465	3232 2346	7543 4333	2333 3233	2113 4364
Ch	0000 0223	3245 4444	1233 1236	6643 3342	2453 2222	2113 4354
Tu	0000 0123	3354 5543	2433 2226	7643 3233	2443 3223	2214 4355
SJ	0100 0322	3245 4544	1243 1236	7633 3333	2342 2222	2214 4364
Hu	0001 1332	3234 4653	1333 2326	6633 5652	1332 3321	1113 6674
Wa	0100 2111	3245 4443	1131 3227	5443 2333	2242 3311	1114 4254

October 1938

	1	2	3	4	5	6	7	8
Si	4765 3333	3334 3222	3433 2333	2215 5110	0002 0000	0111 3120	0257 8764	4677 6332
Ni	5644 2244	3322 3434	3222 1444	2312 4222	0011 0000	0233 2221	0234 6764	5654 4552
Ch	6633 2234	4422 3332	4322 0324	2303 3121	0000 0000	0222 2220	0245 5456	5655 5332
Tu	4744 2133	4332 3333	3322 0443	3313 4231	0001 0000	1222 2221	0244 6535	5654 4333
SJ	5633 2234	3322 3322	4212 0433	3203 3131	0000 0000	1132 2331	0234 6555	6554 4342
Hu	4533 2333	3221 3331	3201 1332	1202 3331	0000 2210	0222 4551	0233 5654	5543 3532
Wa	4744 1223	3322 3322	3321 1333	2212 3211	0001 0000	1232 2221	0144 6664	5664 4332

	9	10	11	12	13	14	15	16
Si	2165 1312	2212 3312	2244 5220	0021 2000	0000 0020	0000 0000	0002 3010	0005 5322
Ni	3123 1334	3312 3133	3311 2230	0011 0133	0112 0133	1000 0001	1112 2022	3222 4333
Ch	4132 1123	3300 1113	3342 2000	0010 0001	0000 0011	1100 0101	0011 1021	2122 3224
Tu	3122 1113	3201 1133	2341 3100	0021 0011	0000 1122	0100 0000	0011 2010	1223 3224
SJ	3132 1323	2200 2132	3321 1000	0011 0000	0011 1221	1101 0000	0112 1021	2223 2223
Hu	2122 2332	2100 2222	2220 2330	0011 0221	0001 1331	1000 0320	0012 3231	2113 4423
Wa	3233 1312	2111 3122	2212 3120	0111 0010	0010 0111	1100 0002	0111 2022	1122 4223

	17	18	19	20	21	22	23	24
Si	2013 1200	0000 0022	1312 3222	2531 1122	1223 3110	0021 1120	0245 4332	2135 6523
Ni	3112 3210	1122 1233	3321 3223	3333 3342	2112 3222	1022 2243	2333 3334	3322 5545
Ch	3001 1221	1111 1122	2321 2233	2432 3232	1212 2121	0022 2132	1344 2333	2333 4435
Tu	4001 1111	1111 0122	2310 2123	2431 2232	0111 2111	0022 2122	1343 3433	3223 5234
SJ	3000 1211	1121 1211	2321 2223	2322 2232	1111 2111	0122 2132	2333 2333	3213 4234
Hu	2002 3421	1112 2332	2312 3333	1213 3432	1002 3331	0012 3331	1333 4532	2202 5534
Wa	3113 2210	1122 0122	3321 1123	2332 2232	2112 2210	0112 2111	1344 2323	2223 5423

	25	26	27	28	29	30	31
Si	4546 7232	2356 7533	4477 7431	2345 7331	2142 1231	2000 0010	0200 0000
Ni	5333 4345	3333 5545	4433 3554	4333 4542	2221 1443	4111 0000	1211 1002
Ch	6545 5344	4343 4434	5344 4433	3343 4332	3241 1222	4101 0000	1200 0001
Tu	5454 5434	2434 5545	3443 4234	3334 4542	3130 1321	3010 0011	1200 0010
SJ	5344 4343	4324 4434	5343 4433	3324 3221	3210 0211	2110 0000	1200 0001
Hu	4233 5543	3223 5553	3334 4553	3223 5431	1111 1432	2010 1310	1100 1110
Wa	3235 5233	2234 4524	4345 4432	3323 4331	2121 0211	2111 0000	1100 0001

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

November 1938

	1	2	3	4	5	6	7	8
Si	0000 3110	0002 2210	0002 0011	1001 0010	0000 1110	0113 3200	0032 1010	0435 6622
Ni	2102 3121	1112 2311	1122 1222	1112 2132	1112 1311	2112 2232	0011 1143	2323 3545
Ch	1111 3211	1101 3211	0001 0122	1111 1121	1000 1210	1212 1211	0221 1112	2434 3434
Tu	2101 3211	1001 2311	0001 0121	1121 1110	1000 1100	1201 1110	0021 1022	2324 4334
SJ	1111 2211	1101 3211	1010 0122	1121 1111	1000 1100	1201 1211	0211 1133	2333 3435
Hu	2102 4331	1112 5422	0011 2331	1122 3220	1001 2330	1210 3420	0011 3332	2213 5635
Wa	1121 3111	1111 2201	1012 1111	1122 1121	0100 1300	1201 1111	0010 1131	1133 3433
	9	10	11	12	13	14	15	16
Si	4557 6633	3311 1010	0000 1210	0000 0000	0010 0000	0000 0222	2101 0012	0012 2001
Ni	5334 4654	4322 1012	1112 2132	2111 0000	2111 1000	1001 2354	3211 1014	2222 2204
Ch	5434 3343	5211 1011	1210 1111	0000 0000	2000 1000	1000 2233	3211 0123	1121 2212
Tu	5444 4434	4221 1011	0110 1111	1000 0000	1000 0000	2101 1333	3110 0123	1121 1112
SJ	5333 3343	4211 1011	2111 1111	0000 1001	2001 2100	1000 1232	3210 0123	1221 2221
Hu	4333 5533	3102 3231	1002 3331	2101 1210	2002 2100	1001 4342	2000 3232	0122 4422
Wa	3223 3643	3221 1010	0110 2111	1101 0000	1000 0001	1110 2222	3211 1022	0131 2202
	17	18	19	20	21	22	23	24
Si	1214 6633	2134 4121	1114 2011	0233 4210	0035 5442	2343 3211	1252 4422	0253 5442
Ni	3213 5655	2223 3143	3223 2232	2112 3332	1124 4545	2433 2322	3323 3324	3334 4543
Ch	2223 5434	2233 3122	3223 1011	1134 2222	2134 4443	3442 3212	2242 3223	2333 3332
Tu	2234 6434	2333 3222	2113 1111	1233 2122	1123 4534	3332 3321	2232 2223	2332 3533
SJ	2324 5344	2223 3211	2112 1121	1122 2122	2123 4424	2422 3221	1132 3223	2223 3432
Hu	2223 7644	1213 4331	1011 3331	1122 3332	1124 5632	3312 3332	1123 4443	1222 3332
Wa	2223 5444	2222 3221	2123 1211	1122 3112	2243 4433	2321 3222	1122 2312	1233 3443
	25	26	27	28	29	30		
Si	2324 4311	2345 5332	1304 3111	0123 3210	0111 0011	1000 0010		
Ni	3322 2432	3344 3433	3223 3212	0123 3211	3221 1213	3011 0110		
Ch	4334 3321	4354 3322	3212 2111	1121 1121	2210 1112	2001 1000		
Tu	3323 3322	4443 3343	3312 2111	0222 1222	2221 0112	2011 0100		
SJ	2222 3321	3343 3342	3212 2011	1111 2121	1120 1221	1011 1000		
Hu	3112 3431	2223 4442	2212 3322	0102 3330	1010 2421	1012 2330		
Wa	2122 2323	2233 3323	2312 1102	1112 1111	2120 1212	2021 1100		

December 1938

	1	2	3	4	5	6	7	8
Si	0000 0010	0025 5444	4444 4443	2200 0010	0313 5201	1133 0011	1000 1210	0000 0000
Ni	0001 0011	1102 3465	5422 3453	4321 0131	2213 3301	2212 2133	1101 1330	1001 0110
Ch	0000 0011	2112 3334	5444 3344	3411 0121	1223 3200	2132 1221	2101 1141	1100 0111
Tu	0001 0011	2113 4454	4243 4353	4211 0122	1222 3121	1222 1122	1100 0051	1000 0001
SJ	0001 0111	2101 3464	4332 3353	3211 0112	1213 3211	1211 1211	1100 0031	1000 1110
Hu	0000 2232	2112 4644	3222 4554	3212 2331	1203 4521	1022 3432	1001 2222	1000 1320
Wa	1010 0021	2213 3235	3332 2444	3322 1121	0212 3211	2211 1112	1100 1121	1001 0110
	9	10	11	12	13	14	15	16
Si	0112 2222	2125 7754	2212 1221	1152 4110	1123 3131	1102 2232	1030 2000	1032 3443
Ni	1312 1433	2223 3664	3233 1212	2223 3211	2222 2242	2213 2343	1211 1122	1223 3465
Ch	1123 2223	2223 4544	2223 1222	2222 3222	2212 2232	2212 1122	2321 1111	1133 3444
Tu	1212 1333	3223 4544	2222 1123	2331 3121	2211 2122	2212 1232	2231 1012	0233 3544
SJ	1212 2223	3223 4454	2222 1222	2231 2223	1212 2232	2112 1233	2231 1111	1233 3545
Hu	1312 2423	3212 4764	2223 3431	1222 4431	1112 3432	2202 3432	1222 3332	0123 4664
Wa	1222 1222	2223 4554	3233 1312	2222 2212	2222 2242	2122 2221	2111 1101	0133 3453
	17	18	19	20	21	22	23	24
Si	3465 4443	3246 6763	1455 6542	2433 5332	1035 5110	2367 6320	0201 3000	1021 0010
Ni	4443 3444	5234 5553	2223 3444	4312 2344	1123 3121	3444 2232	3111 3013	1111 1021
Ch	5444 4435	5254 5443	3443 3423	3332 2334	1233 3112	3355 4222	3300 1011	2120 0011
Tu	5443 4444	4244 5533	3443 3523	3332 2432	1232 3122	3455 4222	2200 1111	1120 0011
SJ	3333 4433	4233 5544	3332 3423	3322 2333	2222 2221	2334 4321	2200 1210	1011 1110
Hu	4223 4553	3134 4563	3221 4442	2211 2451	1122 3332	2324 3433	1100 2221	1010 1222
Wa	4543 3332	3323 5542	3332 3522	1223 2222	1233 3112	2245 3222	1211 2022	1111 0111
	25	26	27	28	29	30	31	
Si	0013 0000	0000 0010	0000 0011	1002 2210	0023 0000	0000 2211	0000 0000	
Ni	2001 2200	1100 0010	0000 0012	2102 2212	0112 1012	2101 1321	2011 0002	
Ch	1001 2000	1000 0000	0000 0001	1101 3222	0112 0002	1100 0111	1010 0000	
Tu	1001 1100	1000 0000	1000 0001	1101 2223	0022 1000	1000 1221	1011 0001	
SJ	1000 2000	1000 0100	1000 0111	2101 2222	1012 1001	1001 0221	1011 0001	
Hu	1000 2221	0000 0210	1000 1222	1002 4323	1012 3211	0000 3332	0011 2211	
Wa	1000 1010	1010 0000	0100 0101	1102 3222	1122 1001	1100 1222	1021 1001	

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

January 1939

	1	2	3	4	5	6	7	8
Si	0012 0000	0112 2100	0012 2000	0000 0010	0212 2221	0003 1222	1104 2211	1202 1121
Ni	1101 1201	0112 2211	2111 2111	0111 0122	2313 3234	3211 2343	2213 3233	3312 2243
Ch	0120 1000	0112 2020	1110 0100	0000 0012	1312 3222	1101 2222	2012 0222	3311 1031
Tu	0020 1000	1012 2121	1121 0100	0100 0112	1422 3222	1102 2212	1112 1223	3311 1121
SJ	1120 1100	1112 2121	1110 1110	0110 0122	1322 3322	1102 1222	1111 1132	3211 1121
Hu	1111 2210	1012 1322	2111 1211	0110 0232	1422 4542	0101 2332	1012 2433	3200 2332
Wa	0121 2100	2123 1122	2221 1110	0110 0111	1322 2223	2122 1212	3223 1123	3312 1221

	9	10	11	12	13	14	15	16
Si	0353 3111	1213 4221	1003 2122	1130 2110	0000 1100	2104 4302	0133 3210	0011 0022
Ni	2332 2124	2313 3232	2311 1344	3201 3212	1102 2202	3212 3314	1312 2211	2002 1243
Ch	1243 1212	1323 3211	1121 1123	1130 2111	1100 1101	3213 2333	1323 1101	1002 1222
Tu	2233 2222	2323 3222	1112 1221	1220 1221	1001 2100	3312 3433	1222 1111	1002 1232
SJ	2132 2223	1222 3222	1112 2222	1110 2221	1001 2100	2312 3313	1221 1211	1002 2233
Hu	2021 2553	1102 3334	1112 2333	0100 2221	1001 3210	2212 3412	2211 2330	0001 3342
Wa	2132 2122	2322 3221	2121 2111	3111 2112	1101 2101	3212 3313	0222 1111	1012 1222

	17	18	19	20	21	22	23	24
Si	2335 5121	2240 0101	0020 2011	1234 0021	1122 4431	0021 1132	2333 4320	0232 2001
Ni	5412 3223	3111 1103	1112 1113	3332 1232	3112 4451	1211 2145	3313 3322	1211 2003
Ch	4333 2132	2330 1002	1210 0023	2332 0122	2112 3231	1221 2244	2434 2110	0432 1011
Tu	5323 3222	2331 0201	1221 0023	3332 0122	2211 3432	1232 2244	2233 3110	0431 0001
SJ	4322 3332	2311 1211	2211 0123	3221 1232	2111 3331	1222 2243	2322 3120	1321 1001
Hu	3213 3332	2210 1311	1100 1232	2111 2342	2111 4443	2111 3453	2221 3332	1331 2112
Wa	3322 3222	2221 1101	2111 1023	3332 0222	2122 3341	2221 2123	2322 3110	1321 1011

	25	26	27	28	29	30	31
Si	0231 2010	0000 2000	0000 0000	0000 1220	1000 0000	0001 0110	0113 1000
Ni	3112 1011	0002 1000	0001 0000	0000 1233	4201 0002	2112 2010	0202 1101
Ch	3321 0001	0000 0000	0000 0000	0100 0222	2000 0000	0100 1012	1303 1011
Tu	2331 0001	1000 0000	0001 0000	0000 1323	2100 0000	0211 0011	2103 2011
SJ	2221 0111	1000 0000	0001 0000	0100 1312	3101 0000	0111 0021	1112 2201
Hu	1211 2222	1000 0100	0000 0100	0100 1432	2111 1010	0111 2311	2102 3322
Wa	2322 1001	0100 0000	0000 0000	0001 1211	2100 0000	0211 0011	0112 2100

February 1939

	1	2	3	4	5	6	7	8
Si	1002 4333	3231 2233	1223 3222	1225 4000	1123 3133	2447 7655	4535 6321	0000 1122
Ni	2112 2354	4312 2354	2312 1234	3313 2121	2113 2244	3334 5555	3522 3352	2101 2124
Ch	2011 3344	5231 2334	1322 1123	3133 1010	0333 2243	3445 4445	4334 3122	2000 1012
Tu	2111 3444	3321 2334	2322 2133	2222 1021	1223 2233	3454 5534	3434 4232	1101 1013
SJ	2012 3455	5331 2334	2221 2232	2212 1101	0111 2233	2334 4534	2222 3231	1002 2223
Hu	2111 3543	4322 4454	2111 3342	2122 2322	1122 3353	3324 5553	2222 3333	1101 2312
Wa	2111 3343	4331 2353	2222 3123	3224 2011	1113 2233	3447 7655	4324 3331	2001 1132

	9	10	11	12	13	14	15	16
Si	2004 4232	2313 3432	2335 4000	0000 1200	0000 1122	1033 3121	1123 2321	1352 4321
Ni	1102 2254	4311 3443	5522 1120	1000 1100	0000 0124	1111 2231	4322 3322	1322 4424
Ch	1103 1233	3312 2222	5533 1000	0000 0000	0000 0022	2131 2232	3332 4222	3432 3323
Tu	1113 2233	2322 3433	5432 2000	1000 0000	0100 0132	2131 2222	2333 3222	3442 4232
SJ	1113 2323	3311 3422	3322 1000	1000 0100	0000 1132	2221 2221	3322 3322	2332 3323
Hu	0213 3422	2212 3552	3221 2100	0011 1210	1000 1332	2111 3432	3222 5543	3321 4532
Wa	1113 1232	3212 3422	4332 1010	0100 1100	0000 0132	2231 2121	2232 3312	2332 3323

	17	18	19	20	21	22	23	24
Si	1134 5421	2033 2221	2133 3120	0000 2310	0200 0000	0022 1020	0000 2010	1323 5765
Ni	2322 3553	3232 3324	2323 3242	2301 0422	1100 0000	0011 1121	4201 2124	2323 3567
Ch	1343 3232	3042 1323	2332 3232	2300 1210	1200 0000	0011 1121	2100 2122	3321 3568
Tu	1233 3232	3232 2224	2332 3133	2200 0221	1201 0000	0011 1121	3211 2122	3422 3666
SJ	1233 3232	2132 2333	2323 3232	2200 1221	1101 0000	0011 1111	2111 2212	3322 3577
Hu	2121 4442	1121 3432	1112 3231	2201 2320	1101 0100	1011 2321	2211 3332	3311 4575
Wa	1324 4322	3122 2312	2322 4222	2300 1301	1200 0000	0011 1110	2100 2112	2333 3577

	25	26	27	28
Si	7488 7533	1000 0111	0000 3210	0122 2421
Ni	6553 6655	1101 1114	1110 2111	1212 2433
Ch	8666 4433	1100 0012	0000 2100	1221 2323
Tu	7556 4334	1110 0123	1100 2010	1122 2433
SJ	7554 5433	2111 1112	0001 2100	1221 1323
Hu	5344 4543	1101 1212	0101 4210	1221 3432
Wa	7564 6543	1111 1112	0101 2100	1221 2333

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

March 1939

	1	2	3	4	5	6	7	8
Si	0125 5443	4545 3121	1324 5423	3464 5433	2124 2222	2345 4222	2102 1011	1355 2121
Ni	4222 3435	5434 3123	3334 3435	5523 4354	3213 2344	2222 3443	3312 2111	3422 2242
Ch	3234 3424	5533 2122	2433 4324	6433 3324	3123 2333	3234 3233	3200 1112	3433 1131
Tu	2234 3425	5533 3122	2433 3233	5443 3443	3223 2233	2344 3233	4211 1111	2433 1122
SJ	3234 3334	5333 2222	2223 3333	5433 4233	3222 2233	2333 3333	2201 1121	3322 1332
Hu	2223 6543	5533 4332	1211 4532	4332 3333	3121 3433	2122 3332	2111 2311	3332 2332
Wa	2233 4434	5533 4212	2443 3334	5433 5343	2223 3223	3333 3423	2201 1212	3433 2142
	9	10	11	12	13	14	15	16
Si	2254 3222	2100 4322	0044 3221	2333 2322	0044 3100	0015 4211	0134 3432	2255 4232
Ni	2343 2241	3212 3213	1122 2523	4223 2343	2012 2101	1113 2213	1223 2432	4423 4444
Ch	2353 2331	3121 2224	1133 3434	3333 2333	3134 2101	0223 2222	0333 3333	5545 3334
Tu	2453 2322	4211 2233	2133 2323	3232 2343	3123 2101	1224 3221	0243 3432	4444 3243
SJ	3443 3332	4211 2233	1133 3323	3321 2333	2113 2101	1223 2222	1233 3432	3223 3233
Hu	3331 3531	3211 3432	2122 4532	2222 4542	2112 3211	1112 3321	0232 4542	3223 4442
Wa	2444 2232	3212 3323	1133 2334	2322 1333	2124 2101	0223 3321	0333 2532	3434 4323
	17	18	19	20	21	22	23	24
Si	2451 2320	0023 1000	0010 0021	2201 0100	0156 4241	2457 5322	3335 4523	2142 4211
Ni	4321 2341	3113 1101	0101 1132	4412 1311	0244 2341	3434 3544	4323 2345	2222 4224
Ch	4450 2231	2112 1100	1000 0132	5411 1211	0355 3352	3433 4443	5323 3333	3332 2223
Tu	3340 2232	1222 1110	0100 0132	4322 1311	1345 3253	3343 4333	4423 3344	2333 2123
SJ	3330 2232	2112 2100	0100 0032	4222 1211	1233 3453	3333 4433	4422 4343	3332 2223
Hu	3220 3431	1112 2210	2111 1232	4211 2411	1234 3463	3223 4433	3311 2332	1211 3332
Wa	2341 2221	1221 1000	1110 0032	3211 1210	1245 4352	3344 3533	4223 4533	2322 4112
	25	26	27	28	29	30	31	
Si	1132 1011	2233 2122	3325 1243	3356 6765	5677 6544	4455 4333	3324 3433	
Ni	2212 2114	4321 2344	5322 1365	4323 5656	5545 5565	4323 3566	5323 3334	
Ch	1321 1023	4233 1033	5424 1244	4332 4456	5755 4445	5442 2244	5423 2334	
Tu	2331 1013	2232 1333	5524 1455	4433 4554	4644 4334	4542 2353	3432 2234	
SJ	2211 1211	3323 1233	2323 3455	4433 4565	4543 3454	4332 2354	4423 3233	
Hu	2221 2111	2222 2332	3312 2464	3423 5664	4434 5643	3321 3443	3321 3433	
Wa	1212 1212	3223 2243	4323 1255	3433 5655	4545 5544	3334 3533	3323 3323	

April 1939

	1	2	3	4	5	6	7	8
Si	3344 4233	3413 3122	2353 4121	2342 1143	3353 4121	0341 1110	0000 0110	1222 3142
Ni	3422 3554	4322 2545	2233 3343	3312 1344	3423 4221	1222 2110	1112 2311	1212 2344
Ch	4433 2334	3312 2234	2343 2233	4341 2144	5433 2122	0341 2121	1121 1221	1220 1153
Tu	4433 2244	3412 2333	3342 2333	3341 2254	3433 3232	1332 1110	1111 1322	1322 2243
SJ	4323 3343	2322 3333	2233 3233	4322 2354	4333 3222	1222 1121	1111 2211	1322 2242
Hu	3222 3433	3322 3433	2222 2442	3321 2353	3232 4332	0221 2122	1111 1321	1210 2354
Wa	3432 5433	3423 4324	2234 2233	2132 1163	3322 4221	1231 1110	1111 1201	1222 2332
	9	10	11	12	13	14	15	16
Si	3222 3233	3455 7344	4247 3333	3564 5123	2152 2120	2113 2132	0023 1110	0021 1002
Ni	3212 3353	6332 4455	4334 3554	3333 3123	3122 3222	2322 2322	1211 2111	1100 0113
Ch	3222 3334	6443 5356	6334 3344	4532 2132	3241 2122	3111 2233	1122 1011	0120 0003
Tu	3212 3333	4443 3455	4234 3443	3433 2223	2232 2322	2222 2333	2221 1011	0010 0114
SJ	2232 2323	4432 4244	3223 3433	4332 3132	2222 2232	2212 3332	2111 1121	1010 0003
Hu	3122 4542	3322 3454	3223 3443	3322 2222	2121 2231	1111 3341	1110 2221	1010 0103
Wa	2122 2232	4444 4344	4334 3433	2332 4112	1242 2221	2222 2321	1221 2210	0110 0003
	17	18	19	20	21	22	23	24
Si	5898 8945	3175 7553	4333 6643	4364 5332	3454 5443	4201 4442	3777 7754	3223 1676
Ni	5665 6665	2243 5555	4343 5654	4332 3433	4322 3433	4301 3554	3675 5653	3112 2686
Ch	5796 6666	2253 5445	4442 5543	5444 3333	3333 2433	4102 2243	3676 5654	3212 0797
Tu	6776 5545	2244 4553	4353 4434	3343 3333	3343 3553	4311 3332	4665 4654	3223 1686
SJ	3576 6534	2234 3333	4333 4354	4332 3233	3232 3323	3211 2332	4665 4432	3212 2485
Hu	5653 7756	2222 4553	3333 5563	3321 3432	3132 2642	3312 3342	3564 5542	2102 2694
Wa	6767 7745	2253 5544	3443 5454	3323 3432	3334 4332	4310 3433	3564 5553	3223 1677
	25	26	27	28	29	30		
Si	6466 6433	4200 0200	1022 0104	3443 3123	2334 3233	1000 2231		
Ni	7543 5544	3210 1211	0001 1205	4322 2333	1333 1332	2010 2341		
Ch	7654 5344	4200 0001	0021 1105	4321 2133	2323 2333	2000 1231		
Tu	6544 4444	3200 1201	1021 0205	3331 2123	2233 2323	2000 2221		
SJ	7433 4332	3210 1101	1011 0104	2321 2133	2322 2223	2111 2221		
Hu	5533 5533	3101 2310	1011 0204	1322 3422	1212 3542	2100 1332		
Wa	6445 4544	3210 1201	1111 0204	4432 3212	2332 3232	1011 2241		

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

May 1939

	1	2	3	4	5	6	7	8
Si	2036 8556	6687 6533	4465 3333	3222 0211	3344 2244	4334 6545	7677 5534	5465 6433
Ni	2135 5455	5444 4434	5323 3432	2213 1221	2212 3365	4334 5545	6544 3333	5444 4343
Ch	2135 6456	6564 3344	4344 2243	3222 1221	2343 2364	3334 5446	5555 4234	6454 4344
Tu	2134 5534	5563 4433	4334 3223	2322 1221	2344 2255	3333 4444	5443 3424	5454 4334
SJ	2135 4454	5453 3454	3233 2233	2212 1221	2322 2254	3333 5434	4453 3233	5333 3233
Hu	2012 5653	5453 4443	3222 3342	1201 1211	2221 3353	3222 5644	4443 3433	5332 5433
Wa	1134 5365	3564 4333	3343 2233	2212 1221	1233 2354	4334 5544	6545 5433	4544 4233
	9	10	11	12	13	14	15	16
Si	4546 4322	2211 1311	2214 3010	0222 2012	0231 3102	1010 2111	1244 4111	4566 2121
Ni	3533 3422	2222 2421	1113 3110	1112 3221	0222 3222	1121 1222	2221 2323	4422 2222
Ch	5634 3322	3211 2322	2213 0011	1231 1112	0132 2213	0220 1122	3333 2223	4564 2131
Tu	3534 3322	3221 1322	2213 2121	1231 1212	1122 2113	1111 1223	2343 2222	4553 2222
SJ	4432 3322	3221 1322	2213 3110	1221 2212	1122 3322	1211 1222	2333 3233	4443 3222
Hu	3322 3321	1221 2421	1102 2110	1121 1121	1010 2211	0110 1321	1131 2432	4433 3231
Wa	3534 3322	2221 1211	1213 3110	1112 3212	1222 3322	1121 2221	2232 3211	4434 2211
	17	18	19	20	21	22	23	24
Si	2211 3223	2312 3312	3552 0121	4554 2322	1222 4444	4467 3423	4565 3335	5541 3434
Ni	2222 2343	3312 2313	3321 1234	3422 3212	2113 3444	4343 3316	3322 2455	5422 3444
Ch	2222 1244	3211 2223	3450 0123	5553 2222	2223 3344	6544 3335	4453 2345	5521 3245
Tu	2322 2343	4321 2213	2441 0223	3553 2333	2233 3344	5454 2235	3453 3334	3432 2344
SJ	2222 1233	3212 2222	3420 1223	3443 2212	2222 3343	4343 3334	3443 3444	4323 4344
Hu	1121 2343	3221 3422	2431 1322	3332 3312	2222 4554	4333 3432	3443 3443	3211 3454
Wa	2222 2332	2312 3312	2331 1233	3323 1212	2122 3433	3444 3434	3343 3334	5432 2434
	25	26	27	28	29	30	31	
Si	4533 3434	4554 3422	3312 1023	6444 4113	4565 7332	1213 3100	1331 0012	
Ni	4423 3545	4322 3433	3311 2235	4343 2224	4454 5444	1113 2111	2211 0123	
Ch	5433 2444	5443 2323	3322 1044	6433 1224	4553 3343	1122 0112	2221 0023	
Tu	4433 3554	4442 2432	3312 1144	5443 2234	4453 4444	2222 1322	2331 0012	
SJ	3333 2344	3221 2332	3312 1144	4432 2223	4454 4322	2111 2221	2221 1112	
Hu	3321 3343	3223 3422	2321 2233	4332 2323	4353 4542	1012 1211	1121 1111	
Wa	3432 3443	3333 3432	3312 2223	4433 3223	4443 4332	1212 2101	2221 0012	

June 1939

	1	2	3	4	5	6	7	8
Si	2211 3433	5534 3433	2346 6232	3442 4221	2232 2212	2311 0111	1010 2100	2110 2110
Ni	3211 5532	4422 4433	3324 3322	4333 4422	2333 4312	1221 2221	2112 2210	2201 2221
Ch	1222 4443	3434 3434	3333 3333	3433 4333	3442 3323	2311 0123	1011 0101	2211 2121
Tu	2222 4533	3443 3324	3332 2333	3432 3322	2342 3222	2322 1112	1121 1221	1211 1111
SJ	2222 3332	3333 3323	2323 4332	2322 3222	2332 3212	2212 2212	1212 1211	1211 1121
Hu	1112 5542	3322 4543	2222 3432	3322 4432	2222 3421	1211 1321	1112 1221	1111 2221
Wa	2211 2431	3433 3323	3344 3322	3432 3322	3332 2321	1231 2211	2221 1110	1221 1110
	9	10	11	12	13	14	15	16
Si	0102 1002	2301 2000	0113 1111	2232 2001	2221 2334	5669 5434	3333 3212	4588 3311
Ni	1101 2102	3412 3211	2112 2122	2201 1112	3312 4444	5555 4333	2312 3323	4544 3321
Ch	0211 0003	3322 2001	0113 2122	1121 1002	3322 2344	5555 4444	3321 2223	4466 3222
Tu	1111 1112	3222 3211	1122 2212	1231 2101	3323 2434	6566 5433	3332 1223	4355 3422
SJ	0211 1001	2212 3201	1111 2112	1121 1111	2323 2334	5443 3334	2321 2222	3346 3222
Hu	1011 2111	2111 3301	1112 2122	1121 1101	2322 2443	5444 4533	2322 3322	3323 4431
Wa	0110 1001	2222 2211	1222 2112	1221 1101	2232 1333	4465 3433	2322 3323	4346 3321
	17	18	19	20	21	22	23	24
Si	0000 0023	3466 5423	4454 3423	4443 4222	4454 3332	3444 1122	3433 3132	3322 1222
Ni	1211 1123	3322 4434	3422 4324	4322 4222	3322 3443	2322 2223	3223 2233	3312 3223
Ch	1000 0124	3434 2234	3343 3334	4333 2223	4453 2243	4432 1223	4423 2333	4321 1123
Tu	1110 0123	4433 3332	2322 3234	5323 2223	4352 3354	3442 1232	3433 2222	3322 2233
SJ	0001 1123	3433 3123	3432 3333	4322 2332	3333 2253	3332 2222	3322 2222	4322 2221
Hu	0011 1222	3422 4332	3332 3433	4322 4431	3332 3342	3332 2221	3322 3332	3321 3221
Wa	1110 1122	3333 3343	3443 4423	4443 3221	3334 3333	2332 2322	3332 3222	3321 2211
	25	26	27	28	29	30		
Si	2120 1111	2312 1133	3444 4312	1214 4333	3544 5422	3344 2223		
Ni	1211 2212	2322 1254	3325 3312	1222 3434	3433 4421	4323 3323		
Ch	2210 1023	3332 1255	3344 3323	1212 3455	3643 3433	4334 2224		
Tu	2220 1121	2332 2245	3443 3333	2322 3345	4543 4432	4334 2223		
SJ	2111 2112	3333 2243	3333 3221	1212 3354	3433 3422	3223 3222		
Hu	2111 3221	2222 2355	2333 3321	1212 4543	3333 4521	2212 2332		
Wa	1221 2112	2332 2233	3344 3322	1223 3334	3533 4422	3334 3223		

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

July 1939

	1	2	3	4	5	6	7	8
Si	3244 3212	3342 3122	4447 8643	3323 3456	6789 8864	5555 1001	1000 2010	1000 1222
Ni	2234 3222	3223 3323	3434 5563	3222 5555	5544 5664	5413 0112	1000 1111	2001 1231
Ch	2244 3223	2342 2233	4455 5543	3431 4467	5677 6764	4533 0012	2100 0021	1100 1243
Tu	3343 2222	1232 2223	3355 4433	3432 4466	6466 4555	4434 0011	1000 0010	1100 1132
SJ	2223 3222	1322 2122	3345 5343	3321 5456	5454 5453	3422 1101	1000 1011	1101 0112
Hu	1122 3222	1322 3321	3344 6543	2322 5565	5443 6783	2411 0100	1000 1010	0100 1331
Wa	2234 2222	2232 2222	3345 5553	2322 3554	5555 4644	3334 1100	1000 1110	1000 0211

	9	10	11	12	13	14	15	16
Si	2000 0000	2100 0110	0002 3341	0102 3422	2110 1031	2357 4523	3335 4212	4244 4443
Ni	3102 2101	2110 1110	0112 5441	1113 5533	1211 0122	2344 5525	3222 2323	2333 4554
Ch	3000 0110	2110 1011	0002 5342	2122 4444	3220 1123	2355 4434	4343 2232	4334 2444
Tu	2000 0110	1010 0010	0014 4332	2112 3323	1120 1122	3344 4434	4342 2222	2344 2443
SJ	1000 0100	2110 0010	0002 4342	1112 3432	1112 1122	3345 4334	4222 2222	2323 2243
Hu	1001 0200	1000 0110	0003 5541	0002 5641	0100 1231	1334 6531	2221 3331	2212 3542
Wa	1000 0100	2110 0010	0112 4231	0112 3321	1221 1121	1244 4323	2333 3112	2332 3253

	17	18	19	20	21	22	23	24
Si	3453 2322	3343 2211	2333 1024	3658 8533	3208 8523	4535 6322	4331 1210	2121 4122
Ni	5352 3324	3212 2322	2211 2225	5533 5534	2204 7522	3424 3424	4222 2321	2222 3332
Ch	4443 3334	3332 2332	3242 1135	4554 4444	3304 6434	5523 3323	4332 1231	2231 3233
Tu	3442 2234	3432 2232	3232 1225	4454 4455	3304 6433	5533 3223	4332 2221	3231 2333
SJ	4432 2223	3322 2322	3232 1224	3454 4344	2304 5323	4423 3333	4332 2211	2221 2122
Hu	3332 4322	2211 2331	2121 2234	2442 6533	3304 7423	3422 3421	3212 3410	2120 3332
Wa	4353 2223	3322 2432	2221 2325	4654 5444	2305 5423	3433 3232	3222 2211	2221 3232

	25	26	27	28	29	30	31
Si	2564 2110	0586 6433	3342 3322	1133 2121	2123 1110	1320 0100	1130 1022
Ni	2332 2221	1443 4534	3222 3414	2222 2322	1212 2221	1212 1200	2211 1122
Ch	3553 2212	2565 3344	3442 2334	2131 1233	1222 1231	1311 0110	0230 1233
Tu	3443 2221	1554 3334	2332 2223	1132 1222	1223 1221	1310 0211	1131 1122
SJ	2343 1211	1353 3333	2322 2223	2232 1232	1211 1121	1311 0211	1221 1111
Hu	3331 2331	1343 3543	1321 3322	1020 2331	0201 2220	1200 1300	0130 1221
Wa	2443 2210	1655 4333	2332 2323	2232 2212	1222 2221	1322 0210	1221 1111

August 1939

	1	2	3	4	5	6	7	8
Si	2321 1010	0110 0000	0000 0000	1101 2011	0001 0000	0000 0000	1011 1110	1000 0130
Ni	2211 2111	1110 0000	0001 1111	0201 2212	0111 1112	1111 1211	1001 2110	1101 1331
Ch	2310 0122	0010 0010	0000 1011	0101 2011	1101 0223	1100 0011	1010 1111	2000 0132
Tu	2321 1111	0110 0100	0000 0011	0010 2111	0101 0111	0010 0111	1011 1100	1000 0221
SJ	2311 1111	0010 0000	0000 0000	0101 1211	1111 0111	1000 0111	1010 1100	1000 1221
Hu	2200 1220	0010 0000	0000 2210	0001 3210	0101 2221	0101 1200	1011 3220	1000 1320
Wa	2211 1110	0110 0000	0000 0001	0101 1100	0111 1111	1000 0100	1001 1100	1001 0210

	9	10	11	12	13	14	15	16
Si	0001 0000	0116 2222	1210 2324	6896 5445	7754 4532	3433 2110	0000 0211	1233 5744
Ni	0112 1011	0214 3432	2211 3435	5665 4445	5433 3433	2322 1211	1111 1322	1213 6745
Ch	0001 0011	0225 3233	2110 2336	6876 3445	5543 3334	4331 1111	1010 0312	1343 5655
Tu	0101 0001	0223 3223	2110 3335	7765 4433	3432 2232	2221 1111	1011 1212	1343 6644
SJ	0100 0110	0223 3333	2210 2225	6754 4335	5422 2333	2332 2110	0010 1312	1333 4444
Hu	0000 1110	0123 4422	1100 3444	6653 4434	4422 3332	2322 2220	0000 2421	1323 5854
Wa	0110 0010	0125 2332	1120 2224	6766 5335	5433 2422	2422 2111	1111 1211	1224 5644

	17	18	19	20	21	22	23	24
Si	4553 4321	2101 2211	1121 2321	1210 1021	1003 3113	8859 8777	6879 8532	2233 3321
Ni	4322 3321	1202 2322	1222 2521	1221 2222	1102 2224	5744 6677	6645 5344	4222 3213
Ch	4533 2221	2101 1122	0131 2311	2221 2233	2112 2124	6644 6667	7665 5333	4154 3222
Tu	5543 2221	2100 0122	0133 3411	2321 2222	2212 1224	7645 6535	5656 5323	4244 3222
SJ	4422 2322	2101 1222	0133 3321	1231 2222	1112 2223	6544 6655	6445 4323	3233 3222
Hu	4322 3320	1000 1111	1021 3510	1221 3431	1101 2333	6533 7654	4444 4432	2131 3320
Wa	4433 2222	1111 1212	1132 3421	1231 2121	1212 2112	6545 7655	6555 5443	2233 4322

	25	26	27	28	29	30	31
Si	2223 3111	1023 3111	2103 3211	0014 2111	1112 1000	0112 3221	0000 0011
Ni	4312 1222	1112 2122	2212 2233	1101 1211	4101 0110	0001 2322	0001 1221
Ch	3422 0113	1112 3012	3201 2123	1013 2012	3202 0010	0011 2232	0000 0122
Tu	3313 1112	1122 2222	3312 2323	1012 1101	2202 0010	0001 2222	1000 1232
SJ	2212 1111	1113 1221	2112 1122	1012 2111	2101 0100	0012 2232	1000 1321
Hu	1201 2210	1101 1210	2200 3322	1001 2220	2101 1120	0001 3531	0001 2430
Wa	3322 2222	0112 2121	1121 2121	0113 2111	2101 1010	0102 2321	0000 1211

Table 1--Three-hour-range indices, K, July 1938 to December 1939--continued

September 1939

	1	2	3	4	5	6	7	8
Si	0000 0010	1000 1223	7744 2333	2101 1010	0000 0001	1131 0032	3223 2011	1103 0102
Ni	0111 1210	1213 2225	5535 3434	3312 3210	0111 0023	3112 2224	2211 2211	1113 1122
Ch	0011 0001	1210 1236	6644 2244	2200 0110	1100 0112	2131 0043	3312 1012	2113 0002
Tu	1010 1210	1211 1225	7645 2334	3311 1110	0100 0112	3131 0142	3222 1121	1112 1212
SJ	0011 0000	1210 1125	6444 2334	3212 1110	0100 0012	2122 0132	2222 1112	1213 1001
Hu	0001 1310	1111 2334	6444 3543	3212 2310	0100 0121	2111 1241	1211 2321	1101 0321
Wa	0100 1200	1221 1224	6454 2334	3212 1110	0110 0021	2211 1223	2221 1112	1212 1212
	9	10	11	12	13	14	15	16
Si	3366 6333	3541 5321	3230 2122	4342 1223	2002 1011	2203 3111	1000 1012	2000 3111
Ni	4342 3343	3222 4342	3221 2111	3332 2224	2103 2113	3222 2323	2112 2114	3211 2231
Ch	4454 3334	4531 2332	3230 1122	4332 2133	2002 1313	4302 2232	2100 1113	2001 2123
Tu	4453 3234	4531 3232	3230 1212	3322 2233	2002 1212	2302 2222	1110 0113	3001 1112
SJ	3433 3344	3322 2332	3230 1111	3222 2223	1101 1222	3302 2222	1201 1122	2101 2122
Hu	3332 3443	3421 4442	3221 2321	3222 2332	1001 2422	3212 3322	1101 2222	2111 3322
Wa	3344 4333	3332 4332	3321 2110	3232 2123	2102 2102	3123 2212	2111 1112	2211 2111
	17	18	19	20	21	22	23	24
Si	2655 5764	2204 1100	1257 5733	3687 5331	2233 2112	2334 3321	0021 0011	0433 1110
Ni	2433 4574	3212 2110	2323 4545	5433 3442	2222 2232	2223 1314	1013 1123	2211 2111
Ch	2542 4464	3212 1100	3354 4444	3654 3232	3332 2132	3323 2322	1000 0012	1322 1020
Tu	3543 4543	3212 1211	3354 4434	3553 3321	3322 2222	2323 2313	1011 0112	2312 1010
SJ	3432 3634	3222 1211	3344 4334	4533 3222	3232 2232	2312 2322	2010 0012	2212 1011
Hu	3333 5653	3222 3310	2234 5653	3433 4441	2323 3322	2222 3432	0011 2221	2212 2220
Wa	2443 5465	3222 2210	2324 5433	4334 3322	2332 2322	1233 2212	1111 0112	1222 1121
	25	26	27	28	29	30		
Si	0224 3322	3535 3222	1000 0121	2010 0010	0000 0000	0003 1122		
Ni	1013 2233	4433 2253	1111 0143	2111 1121	0011 0101	0112 1133		
Ch	0223 2124	4423 1232	1100 0032	2010 1010	0011 0110	1012 0033		
Tu	0223 2324	5423 2222	1110 0221	2110 1011	0011 0110	0113 1033		
SJ	0123 2223	4322 2231	1100 0122	2000 1021	0111 0210	0112 1143		
Hu	0123 2332	4312 3431	1111 1232	2110 2330	2022 1321	1012 1242		
Wa	1113 2322	4323 2142	1111 1221	1121 1210	1110 0111	0113 1233		

October 1939

	1	2	3	4	5	6	7	8
Si	1000 1220	0010 0112	2156 7455	7734 6221	1325 5241	3765 4232	1011 1332	2120 0031
Ni	3111 2323	1121 1222	2123 5556	6632 3242	3222 2252	4622 2342	1101 3454	3311 2233
Ch	3200 2331	0110 1223	3234 5354	7731 3333	2314 2132	4654 2244	2101 3333	4210 2132
Tu	3210 2331	1221 1123	3234 5554	6632 4233	3324 3242	4654 2343	2101 2333	3220 1232
SJ	4210 2332	1021 2233	3234 4564	6521 3332	2213 2342	3543 2244	2102 3333	3210 2232
Hu	3213 3431	0121 3343	2234 6564	6523 4431	2214 4431	3533 3442	2002 4431	2110 3342
Wa	2111 2222	1221 2222	2225 4563	6522 5332	2324 3243	3443 3432	2122 2232	2210 2223
	9	10	11	12	13	14	15	16
Si	2163 7310	0000 1101	1202 1032	2000 0000	3775 3567	4687 8533	6774 3322	2364 5633
Ni	4253 4242	1112 3103	3312 3144	3200 0101	5553 4676	5555 5654	6642 3653	3322 4655
Ch	3263 5221	1011 1112	2311 3043	2100 0011	5453 3467	6566 4443	7773 3332	4444 4335
Tu	2363 4221	1111 2213	3211 2133	2100 0001	5554 3566	4665 5433	6773 3432	3333 4433
SJ	3253 4221	1112 2223	1322 2233	2100 0111	5553 4675	6454 4443	5653 4423	3233 5534
Hu	2243 5420	1111 3321	1311 4352	2100 1221	5554 5665	3254 4543	4652 3432	3122 4643
Wa	2363 5331	1221 2112	2312 2223	1000 0101	4464 3576	4556 7433	5753 4442	3332 5543
	17	18	19	20	21	22	23	24
Si	3556 5542	2356 6632	2456 3331	0034 0000	1122 5332	1000 0121	0035 6421	1111 0110
Ni	3433 3554	4333 3554	4323 2342	3121 0110	0222 2144	2121 1143	0122 4523	4222 1111
Ch	4654 3444	5344 2333	3534 2121	2112 0010	0231 2234	1010 1032	0223 2332	3110 0011
Tu	3543 3343	4344 3333	3534 2222	2123 1010	1232 2234	2121 1123	1222 3323	3220 0122
SJ	3432 3543	3233 4323	2424 2232	2121 1110	1232 3234	2121 1232	1222 3332	3210 0221
Hu	1323 3553	2232 3541	1323 3431	1210 1220	1231 4352	1121 3333	0311 2440	2110 2221
Wa	3443 3543	3343 4433	3334 2332	1121 1110	1232 3233	2221 1132	1223 5423	3222 1111
	25	26	27	28	29	30	31	
Si	1121 2010	0021 0020	0000 0200	0034 4111	2312 1111	1230 3211	1132 3110	
Ni	1212 2110	1122 1142	0101 1201	0123 2123	3211 1132	3102 2233	4111 2111	
Ch	1120 2010	1020 0031	1100 1211	0012 2122	3322 1111	3100 1112	2120 1211	
Tu	2110 2110	1021 0132	1110 1321	0112 2012	4322 1121	3210 1123	3121 1111	
SJ	2111 2210	1111 1223	2121 2221	0122 2212	3211 3221	3211 2112	2221 2211	
Hu	2100 4220	2011 1342	2012 3421	0233 4321	3211 3321	3112 2330	2211 3332	
Wa	2221 3110	1122 1132	2111 2211	0133 3212	2221 2221	3221 3212	2111 2221	

Table 1--Three-hour-range indices, K, July 1938 to December 1939--concluded

November 1939

	1	2	3	4	5	6	7	8
Si	0044 3220	0322 2110	0023 3111	1032 1011	0014 1100	0001 1112	1020 0210	0002 1100
Ni	3111 1131	1212 1111	3111 2113	2102 1101	1012 2220	1112 1223	2212 1332	1111 2010
Ch	2133 2221	0221 1010	2212 1111	1021 0011	1113 2110	0010 1022	2111 1111	0011 2020
Tu	2122 2221	1321 1010	1112 3222	2122 1012	2113 1220	1111 1133	2111 1112	0012 2010
SJ	1122 2221	1221 2121	2212 3222	1122 2121	1112 2211	1122 1222	2112 1321	0111 2121
Hu	2012 4430	1212 3220	1102 3332	1111 2220	1111 3320	0101 3431	1012 2330	0000 3220
Wa	2112 2231	1221 1011	1112 3222	2112 2221	1113 2221	1222 1222	2221 1221	1111 2121

	9	10	11	12	13	14	15	16
Si	0121 0000	0001 0100	0001 0011	2005 4211	2567 7534	3444 4322	2132 3220	0021 0000
Ni	1211 0211	1111 1121	2200 1243	[illegible]02 3222	3534 4454	5323 2434	2221 2432	2101 1321
Ch	0201 0000	1100 0000	2200 0112	[illegible]003 2112	3455 5344	6422 3223	2120 0220	1010 1000
Tu	1222 0001	0200 1000	1200 0022	3114 3212	3445 4545	4432 3314	2231 2211	1020 1101
SJ	1212 0111	0100 1100	1101 0123	3113 3223	4335 3435	3422 3323	1121 2221	1001 2211
Hu	0100 2420	0000 2320	0000 1322	3003 5431	3224 5543	3312 4533	1122 3430	0001 2211
Wa	1222 1211	1110 1110	1211 0132	2123 3312	2455 5433	3323 3233	2221 2321	1111 1321

	17	18	19	20	21	22	23	24
Si	0021 1010	0032 0000	0000 2322	2212 0011	0032 2000	0000 0000	0010 0000	0000 2121
Ni	1012 1142	1112 0111	0002 3432	3211 0122	1113 2110	0000 0002	0111 1011	1101 3234
Ch	0000 0110	0111 0011	0001 4332	4320 0011	1121 2110	0000 0000	0111 0011	0200 2223
Tu	0011 0120	1212 0011	0102 2432	2221 0122	1121 2120	0100 0000	0121 1022	1210 2333
SJ	1112 1221	1222 1111	1101 2422	2211 0122	1011 2110	0000 0000	0121 1122	1201 3333
Hu	0102 2330	0211 2321	0002 5532	2100 1332	1122 3230	0000 2210	0122 3332	1201 4442
Wa	1011 1121	1222 0111	1113 2333	2221 1122	1121 1210	0100 0001	0122 1111	1111 2223

	25	26	27	28	29	30
Si	1444 3334	2435 3211	1223 3020	0334 3000	0013 2211	0122 2010
Ni	3431 2355	3323 3252	1312 1122	1211 2120	1111 1213	1211 1223
Ch	4443 2334	3434 2121	0322 1120	0412 2000	1013 0001	1211 1111
Tu	3343 3354	3433 3231	1212 1231	0322 2111	1122 2122	1122 1112
SJ	3332 2344	3322 3222	1211 1111	0202 1220	1001 1221	2211 1212
Hu	2212 4544	2222 4331	1111 2231	0201 3321	0001 3321	1112 3322
Wa	3432 3333	2243 3232	1222 1221	1222 2220	1122 1312	1221 1222

December 1939

	1	2	3	4	5	6	7	8
Si	0123 2011	0031 1211	1011 1012	1110 0000	0010 3432	2100 1144	5476 7642	2465 5532
Ni	2332 1132	2122 1133	1111 1124	3100 1002	2101 2443	4221 2166	5543 5535	3432 3654
Ch	1331 1121	1120 0122	0120 0013	3020 0000	0000 1223	3122 1055	6544 4433	3554 3433
Tu	2333 1132	1221 0222	0222 1113	2120 1011	1111 2323	2122 2165	6554 4434	4543 4442
SJ	2332 1221	1131 0212	0222 1223	3022 0111	1110 2223	3222 2263	5353 4434	3433 3432
Hu	1222 2431	1021 2332	0211 1323	2020 2211	1011 3533	2011 3354	4444 4542	3222 5542
Wa	2332 2232	2221 1222	1221 1113	3110 1011	1112 3332	3222 2243	5654 5433	3343 3533

	9	10	11	12	13	14	15	16
Si	2044 5320	0223 3211	1133 3110	2122 1312	0212 2200	0032 1000	0321 1311	0101 0113
Ni	4222 3351	1112 3333	2111 2112	2101 1324	2211 2200	2000 0001	2221 2321	1101 1325
Ch	4234 3331	1322 2112	3233 1111	3221 0223	1211 1000	2020 0102	1321 1214	1200 0214
Tu	3233 3331	2212 2222	1332 2211	2111 1312	1211 1100	1010 0111	1322 1212	0010 1314
SJ	3223 4431	2213 3222	2223 2212	3211 1323	1211 1201	0010 0211	2221 1211	0112 1225
Hu	2113 4430	1101 3322	2112 3321	2111 1432	0101 3210	0010 1221	1212 3431	0001 3623
Wa	4333 4332	2222 3312	2132 2221	2122 2223	2222 2100	1011 1111	2222 2322	1022 2323

	17	18	19	20	21	22	23	24
Si	2021 0110	0002 0000	0100 0000	0000 0010	0455 5422	2435 6531	0244 2120	1333 2212
Ni	3112 1112	2000 0000	0100 0000	0000 1122	1223 4443	4222 4544	2322 2214	3222 3322
Ch	3012 0001	2100 0000	0200 0000	0000 0122	3454 3333	4433 4323	2433 0102	3343 1022
Tu	2121 0010	1100 0000	0100 0000	0000 1211	3454 4333	4423 4433	2332 1212	2221 2221
SJ	2112 1111	2110 0000	0110 0100	0000 2222	3334 3233	4333 4322	2323 2212	2232 3022
Hu	1012 3211	0101 0110	0000 1100	0000 2331	3333 5653	3323 5531	1212 3421	1111 1332
Wa	2222 3201	0010 0000	0011 0000	0000 2211	1244 4333	3343 4432	2332 2212	3232 3323

	25	26	27	28	29	30	31
Si	2122 3110	0222 1010	0144 2232	1023 3121	1212 2321	1012 2201	0112 0000
Ni	3201 2123	2211 1012	2213 3442	1212 2233	3213 2332	3202 2311	1200 1000
Ch	3221 1111	1220 0010	2333 2232	1223 1122	3222 1121	2111 0211	0110 1000
Tu	3211 2112	1221 1011	2333 2232	1122 2132	2222 2222	2211 1221	1100 0000
SJ	1100 2111	1221 1011	2332 2322	1222 2232	2322 2321	2211 1211	0101 0100
Hu	1000 2332	0211 2232	2332 4652	1112 2443	1112 3542	1101 2311	0101 1110
Wa	2111 2122	1122 2111	2343 2343	2223 3332	3323 3332	2222 2322	1200 0010

Table 2--World-wide magnetic three-hour-range indices, K_W, 1938-39

Day	January 1938									February 1938									March 1938								
	Values K_W								Sum	Values K_W								Sum	Values K_W								Sum
1	3	2x	1	2	1x	1x	2	2	15x	1x	2	1x	2	3x	2	2	2x	17	3x	3x	3	3	4	3	3x	3	26x
2	2	1x	1x	2	2x	2x	2	2	16	2x	2x	2x	3	2	1x	1x	1x	17	2x	1x	2x	2	1	1	1	1x	13
3	3	1	1x	1x	2	2	2x	0x	14	3	2x	2x	2x	2x	3	2	2	20	2	2	1	0x	1	1	1	1	9x
4	2x	2	2	2x	5	4	5	3x	26x	2	1x	2	2	2x	3	3	2	18	0x	1	1x	0x	0x	1x	2x	3x	11x
5	3	3	2x	3x	0x	0	0	0x	13	2x	2	1x	2	2x	1x	1	0	13	2x	2	4	3	4x	4x	4	3	27x
6	0x	0x	1	2	2x	4	3	2	15x	2	6	5x	3	3	4x	4x	3x	32	4	3	3x	2x	1x	2	2x	3	22
7	3	2x	1	1	2x	3x	4	4	21x	3x	3x	2x	3	4x	4	2x	2x	26	2	0x	2	2	3	2	1	0x	13
8	4x	5	3	2	0x	0	0x	3	18x	2	2	2x	3	3x	5x	5x	4x	28x	1	1x	1	1	0	1	0	1	6x
9	4	2x	2	1	1x	0x	1	0x	13	3	4x	3x	4	4	4	3x	3	29x	0x	1	0x	0x	0x	0x	0x	1x	5x
10	1	1x	0x	0x	1	0	0x	0	5	4	5	5	3x	3x	0x	0	2	23x	1	1	0	0x	1	0	0x	0x	4x
11	1	0x	1x	1	1	2	1	0x	8x	4	4x	5	4x	1x	2x	2	1	25	0	0x	1x	0x	0	0x	0x	2	5x
12	0x	1	3	1x	1x	3	3	4	17x	1	1	3x	2x	2x	1	1	2	14x	3	3	3	3	3	3	1x	1x	21
13	5	4x	5	3x	2x	2x	2x	1x	27	3	2	2x	3	2x	2x	3	3	21x	1	1x	0x	0x	1	1	0x	1	7
14	0x	1x	3	1	3	1x	1x	1x	13x	3	3x	4x	4x	5	4x	3	1	29	1x	3	3	2x	2x	2	2	2	18x
15	2	2x	3	2	2	2	2x	2x	18x	0	1	1x	1	0x	0x	1	1x	7	2x	2x	2	2x	3	1x	1x	0x	16
16	1x	1	2x	2x	2x	3x	2x	6x	22x	1x	0x	2	1	1	0	0x	1x	8	0	0	0	1	0	0x	0x	1	3
17	5x	5x	5x	6	7x	6x	4	6	46x	0	0	2	1x	1	0x	1	1x	7x	2	1x	1	1	1	1x	0	0x	8x
18	4	3x	3	2x	3	4x	4	4	28x	0x	2x	2	1x	2	2	1	1	12x	0x	0	0x	0x	0x	0	0x	0	2x
19	3x	3	3	3x	3x	4	3x	2	26	1x	0	0	0	0	0	0x	1	3	0	0	0x	0	0	0	0	0	0x
20	1x	3x	3	3x	3x	3	4x	3	25x	0	1	2	0	1x	0x	0	1	6	0	0	0	0	0	0	0	1	1
21	3	4x	5	4x	4x	3x	3	4x	32x	1	1	1	3	0x	0	0	0	6x	1	0x	0	1	2x	1x	2	4x	13
22	5x	6x	8	9	6x	6x	4x	4	50x	0	0	0	0x	0x	0x	1	1x	4	3x	4x	5	4x	4	4	3	4	32x
23	3	2x	2x	3	2	2	3	3x	21x	3	2	3x	2x	3	3	2x	2x	22	4x	4	4	5	2	3	4x	5	32
24	2x	3	3	2x	2	2x	2x	2	20	1	2	2x	1x	2	1	1x	2	13x	5x	5	4x	4	2x	1x	2	2	27
25	3x	2	1x	4x	6	6x	8x	8	40x	1x	0x	2	3x	3	3x	3x	1x	19	1x	1	2x	3x	3	1x	2x	3x	19
26	7	5x	3x	4x	3x	4	3	1x	32x	1x	1x	1	2	2x	2	3	2	15x	5x	2x	1x	3x	3	3	2	2	23
27	1	0x	2x	1x	2	3x	2x	2	15x	2	1x	1	1	2x	2x	2	3	15x	3	1	1	0x	0x	0x	1x	0x	8x
28	1	2	1	1x	2x	1x	2x	2	14	3x	2x	3	3	2x	2	3x	3x	23x	1x	1x	0	0x	1	0	0	1	5x
29	1x	2x	2	3	1	0x	3	4	17x										1	0	1x	2	1x	3	3x	1x	14
30	2	1	0x	0x	0x	0x	2	2x	9x										1	1x	1	0x	0	0	0	0	4
31	2x	1x	3x	4	3	4	5	5	28x										0	0	0x	0x	0	0x	1	1	3x

Day	April 1938									May 1938									June 1938								
	Values K_W								Sum	Values K_W								Sum	Values K_W								Sum
1	0x	0	0	2x	1	2x	2x	1x	10x	0x	0x	0x	1	0	0x	2	2	7	1x	1	2	1x	1x	1	1	1	10x
2	0x	0	0	0x	0	0x	2	1x	5	1x	2x	1x	2	1x	1	1	1	12	1x	1x	1x	1x	2	2x	3x	4	18
3	1x	0x	0	1x	2x	2x	2	1x	12	1	3	2	3	1	3	3	3	19	3x	1	1x	1x	0x	0x	1	1x	11
4	2	2x	1x	2	2x	2	1	0x	14	3	4x	3	2	3x	6	4x	2x	29	2	2	0	1	0x	0x	0	0x	6x
5	0	1	0x	0x	0	0	0	0	2	4	3	1x	2x	1x	3x	3	3	22	2x	2	2	2x	1	1x	1x	0x	13x
6	2	3	4	3x	2	1x	3	3x	22x	2	2x	2x	3	2x	2x	1x	0x	17	1	0x	1	0x	2	2x	2	0x	10
7	3x	3x	2x	3	3	2x	1	2	21	0x	0	1x	1	0x	2	0	0	5x	0x	1	0x	0x	1	1	1	4	9x
8	1x	2	1x	2x	1x	2x	1x	2	15	0x	1	1	1	2	1	1x	1	9	3x	4	4x	4	3	3x	4x	4	31
9	1	1	1	2x	4	2	2x	2	16	1	0	0	0x	1x	1x	1x	2x	8x	2	2x	3	1	2	2x	2	2	17
10	2	1	1x	2x	2	2x	1	0x	13	3	2x	2	1x	1x	1x	1	1	14	1x	1x	2	3	2x	3	3	2x	19
11	1	1x	1x	3	2	4	2x	3x	19	2x	2	2	2x	2	6x	7x	7	32	3	2x	2x	3	2x	2x	3x	3	22x
12	1x	2	2x	3	3	1	3x	3	19x	6x	5x	5x	4	4	3x	4	4x	37x	3x	3	3	3	1x	4x	5	4	27x
13	2	1x	2x	4x	4x	4x	3x	5x	28x	4x	1x	1	0x	1x	1	1	2	13	3x	4	4x	4	3	3	3	3	28
14	5	5	6	5x	4x	3x	4	3x	37	3	2x	2x	5	4x	4	3x	5	30	3x	1	1x	0x	0x	0x	0	1	8x
15	3x	3	2x	2	3	3	2	1x	20x	4	4x	2x	2x	2	3	1x	2	22	1x	1	0	0	0	0x	1	0x	4x
16	2x	6	9	7x	6x	5	3	4x	44	2x	3	3x	3	2x	3	3	2	22x	0	0x	2x	2x	2	2x	2	1x	13x
17	2	2	2x	2x	2x	2x	3x	3	20x	3	2x	3	3	1x	2x	3	2	20x	1x	1x	1	0x	0x	1	3	1	10
18	3x	2x	3	2x	2	3	2x	3	22	1x	2x	2x	1x	1	0x	1	0x	11	1	1x	2	1x	1	1	1	1	10
19	3x	2	1x	2	1x	2x	1x	2	16x	1	1	1	0x	0x	2x	1x	1x	9x	0x	1x	1	0x	1	2x	1	0	8
20	2	1x	1	0x	2	1x	1x	1	11	1	1	0	0x	0x	0x	0x	1x	5x	1x	0x	0	0x	0	0x	1x	2	6x
21	2x	1x	1x	1x	1	1x	2	1x	13	0x	1x	2	2x	1x	1x	0x	1	11	2x	2x	3	3	2x	1x	1	0x	16x
22	2	2x	1	1	2x	3	3x	3	18x	1x	1	1	1x	1	2x	2	1	11x	1x	2	2x	2	1	1	0x	0x	11
23	3	2	4	4x	4	4	4	4	29x	0x	1	1	0x	0	0x	0x	0x	4x	0	0x	0	0	0	0	0	0	0x
24	3	3	2x	3	2	2	2	1	18x	0x	0x	0x	2x	3	4	3	3x	17x	0	0	2	1	1	1	1x	1	7x
25	3	3	3	3x	3	2x	2x	2	22x	2x	3	1x	2	1x	2	2	2x	17	1	1	0x	0x	1x	1	0x	1	7
26	2	1	1x	3	2x	2	0x	1	13x	1x	2	1x	1	1	1	0x	0x	9	1	1x	2	1x	1x	1	1	0x	10
27	1x	2	1	1	1	2	1	1x	11	1	1	1x	1	1	2x	2	1x	11x	1	1	0x	2	0x	1	1	1	8
28	0x	1	0	1	0x	1x	0	0	4x	1x	1x	4	2x	2x	3	3	2x	20x	0x	0	0x	0	0	0x	1x	1	4
29	2	2	1	0	0x	0x	0	0x	6x	2x	3	4	3x	5	4	3	3	28	1	1	1x	0	1	1x	3	1x	10x
30	0	0	0	1	1x	2	0x	0x	5x	2	1	2x	2x	3	1	2x	1x	16	1x	2	1	2	1x	1x	1	1	11x
31										1x	1	2	2	0x	1x	2	1	11x									

Table 2--World-wide magnetic three-hour-range indices, K_W, 1938-39--continued

Day	July 1938									August 1938									September 1938								
	Values K_W								Sum	Values K_W								Sum	Values K_W								Sum
1	2^x	3^x	3^x	3^x	3^x	3	2^x	3^x	25^x	1	1	3	3	2^x	4	3	4	21^x	0^x	1^x	1^x	0^x	0^x	1^x	1^x	1	8^x
2	2^x	3	2^x	2^x	2^x	2	1	0^x	16^x	3^x	5	2^x	2	2	2^x	3	4	24^x	0^x	0^x	1	1	0^x	0^x	0^x	2	6^x
3	0^x	2	1^x	0^x	0^x	1	0^x	0	6^x	3	2	1^x	0	0	2^x	2^x	6^x	18	2	2	2^x	3	2	2^x	1^x	2	17^x
4	1^x	2	2	1^x	4^x	4	5	5^x	26	4^x	4^x	6	5	3^x	4	3	3^x	34	0^x	0	1	1^x	2	2^x	1^x	2^x	11^x
5	4	3	2	2^x	4	2	2^x	1^x	21^x	3^x	4	3	2	3	3	3^x	2^x	24^x	2	2	1^x	2	3^x	3	0^x	0	14^x
6	2^x	3	2	2^x	3	2^x	2	0^x	18	3^x	2^x	2	2	1	2^x	2	1^x	17	0	1^x	0	1^x	1	0	1^x	2^x	8
7	1	1^x	1	0^x	1^x	1^x	1^x	1^x	10	1	2^x	2^x	1	2^x	3	2	1^x	16	1^x	2	1^x	1^x	1	3	2	0^x	13
8	2	1^x	1^x	1^x	2	1	1	0	10^x	1	1^x	2	2	1	0	1^x	1^x	10^x	2	1^x	1^x	1^x	2	2	2	1	13^x
9	2	0^x	1	0^x	0^x	1^x	3^x	3^x	13	1	0^x	0^x	0	2	0^x	0^x	1	6	0	1	2	2	2^x	2^x	2^x	1	13^x
10	4	3	3	2^x	3	3^x	4^x	3	26^x	1	3	2^x	2^x	2^x	2^x	2	2	18	1	2	2	2^x	2^x	2	1^x	1	14^x
11	3	2	1	1	0^x	0^x	1	1	10	2	3	3^x	5^x	5	4^x	3^x	3	30	2	2	0	2	2	2	2^x	1^x	14
12	1^x	1^x	1	1	2	1^x	1	1^x	11	2^x	2^x	2^x	3	2^x	2	2^x	2	19^x	1^x	2	2^x	1	2	1^x	2	2	14^x
13	1^x	1^x	2	2	2	2^x	3	4	18^x	2^x	3	2^x	1	1^x	0^x	1^x	0^x	13	1^x	3^x	2	1^x	1	2	4^x	4^x	20^x
14	4^x	3^x	1^x	2	3	2	3	2^x	22	1	1	0	0^x	2	1	1	0^x	7	4^x	4^x	2	2	3^x	5	4^x	4^x	30^x
15	1^x	3^x	4	4	4^x	5	6	5^x	34	0	0	0^x	0	0	1	0^x	0	2	5	5	5^x	6	6	5	5	4	41^x
16	4^x	3	2^x	4	3^x	2^x	4^x	2^x	27	0	0	0^x	0	0	0	0	0	0^x	3^x	2^x	1^x	1^x	1^x	1^x	2	2^x	16^x
17	1^x	2^x	2^x	0^x	0^x	0	0^x	0^x	8^x	0	0	1	0^x	2	1^x	0^x	0^x	6	2	3^x	1^x	1	2^x	2	1	0	13^x
18	0	1	0^x	1	1	2	1	1^x	8	1^x	0	0	0	0	0^x	1	0^x	3^x	1^x	1	2	1^x	1^x	1^x	0	1	10
19	3	1	2	2^x	1^x	1	1	1	13	0^x	0^x	0^x	0^x	0^x	1	1	0^x	5	1	1	1	0	0	1	1	1^x	6^x
20	1^x	1^x	2	1	1^x	2	1^x	2	13	0	0^x	0^x	0^x	0	0^x	0^x	1	3^x	2	1	2^x	1^x	2	1^x	0^x	0	11
21	2	1	1^x	1^x	1^x	1^x	1	1	11	0	0^x	0^x	0^x	2^x	2^x	2^x	1	10	0^x	1	2	1^x	1	1^x	3	2^x	13
22	0	1^x	2	1^x	0^x	1^x	1^x	0^x	9	1	1^x	0^x	0	4	3^x	4^x	2^x	17^x	2^x	2^x	3	3^x	2	2	1	0^x	17
23	1^x	1	1^x	0	1	1^x	1^x	2	10	3	3	3	5	4^x	2	2^x	1^x	24^x	1^x	3^x	3	1^x	1	1	1	1	13^x
24	1^x	0^x	0^x	1	1	1	1^x	1^x	8^x	1^x	0^x	1	1^x	2^x	1^x	3	3^x	15	0^x	0^x	0	0	0^x	0^x	0^x	1	3^x
25	2	0^x	0	0	0	0	0^x	0	3	3	1^x	1	0	0^x	1^x	2	0^x	10	0	0^x	0	0^x	1	2	1^x	2	7^x
26	0	0	0^x	0^x	1	0^x	0^x	0	3	0^x	1	0^x	0	0	0	1	1	4	3	2	4	5	4	4^x	4^x	4	31
27	0	1^x	1	0	1	1	0^x	1^x	6^x	0^x	0	0^x	1	0	0^x	0^x	0^x	3^x	2	2^x	3^x	2^x	2	2^x	2	6	23
28	0	0^x	0	0	0^x	1	0	0	2	0^x	0^x	0	0^x	0^x	3	3	2^x	10^x	6^x	5^x	3^x	3	3^x	3	3	2^x	30^x
29	0	1	1^x	2	2^x	2	2^x	3	14^x	2	2	3	2^x	0^x	0^x	3^x	2	16	1^x	3	4	3	3	2^x	1^x	1^x	20
30	3	5	5^x	4^x	4	2^x	4	3^x	32	2^x	3^x	1	2	2	1	2	0^x	14^x	1^x	1^x	1^x	3^x	4	3	5^x	4	24^x
31	3	1	0^x	1^x	0	0	0^x	0	6^x	1^x	2	1^x	1^x	1^x	0^x	0	0	8^x									

Day	October 1938									November 1938									December 1938								
	Values K_W								Sum	Values K_W								Sum	Values K_W								Sum
1	4^x	6	4	4	2	2	2^x	3^x	28^x	1	1	0^x	1	2^x	1^x	1^x	0^x	9^x	0	0	0	0^x	0	0	1^x	1	3
2	3	3	2^x	2	3	3	2^x	2^x	21^x	1	1	0^x	1^x	2^x	2^x	1	1	11	1^x	1	1	2^x	3	3	4	4^x	20^x
3	3	2^x	2	2	1	3^x	2^x	3^x	20	0^x	0	1	1^x	0^x	1	1^x	1^x	7^x	4^x	3^x	3^x	2^x	3	3	4	3^x	27^x
4	2	2^x	0^x	2^x	3^x	1^x	1^x	1	15	1	1	1^x	1^x	1	1	1^x	0^x	9	3^x	3	1^x	1	0^x	1	2	1	13^x
5	0	0	0	0^x	0	0	0	0	0^x	0^x	0^x	0^x	0^x	1	2	0^x	0	5^x	1	2^x	1^x	2^x	3	2^x	0^x	1	14^x
6	0^x	2	2^x	2	2^x	2^x	2	0^x	14^x	1	2	1	1^x	1^x	2	1	0^x	10^x	2	2	2	2	1	1^x	1^x	1^x	13^x
7	0	2	3^x	4^x	6	5^x	5	4^x	31	0	0^x	1^x	1	1	1	2	1^x	8^x	1^x	0^x	0	0^x	1	1^x	1^x	0^x	7
8	5	5^x	5^x	4^x	4	3^x	3	2	33	1^x	3	2^x	3^x	3^x	4	3	4	25	1	0	0	0^x	0	1	0^x	0^x	3^x
9	3	1^x	3	3	1	2^x	1^x	2^x	18	5	3^x	3^x	4	3^x	4^x	3^x	3^x	31	1	2^x	1^x	2	1^x	2^x	2	2^x	15^x
10	2^x	2	0^x	1	2	1^x	1^x	2^x	13^x	4	2^x	1^x	1^x	1	0	1	0^x	12	2^x	2	2	3	4	5	4^x	4	27
11	2^x	2^x	2^x	1^x	2^x	1	1^x	0	14	0^x	1	1	0^x	1^x	1^x	1^x	1	8^x	2^x	2^x	2^x	2^x	1	2	1^x	2	16^x
12	0	0	1^x	1	0^x	0	1	0^x	4^x	1	0^x	0^x	0^x	0	0	0	0	2^x	2	2^x	3	2	2^x	2	1^x	1^x	17
13	0	0	0^x	0^x	0^x	0^x	1^x	1	4^x	1^x	0	0^x	0^x	0^x	0	0	0	3	2	2	1^x	2	2	2	3	2	16^x
14	0^x	0^x	0	0	0	0^x	0	0^x	2	1	0^x	0	0^x	1^x	2	3	2^x	11	2	2	1	2	1^x	2	2^x	2	15
15	0	0^x	1	1^x	2	0	1^x	1	7^x	3	2	1	0^x	0^x	0^x	1^x	2^x	11^x	2	1^x	2	1	1	1	1	1	10^x
16	1^x	1	1^x	2^x	3^x	2^x	2	3	17^x	0^x	1	2	1^x	2	1^x	0^x	2	11	0^x	1^x	3	3	2^x	4	4^x	4	23
17	2^x	0^x	0^x	2	2	2	1	0^x	11	2^x	2^x	2	3^x	5	4	3^x	4	27	4^x	4	4	3^x	3^x	3^x	3^x	3^x	30
18	1	1	1^x	1^x	0^x	1^x	2	2	11	2^x	2^x	2^x	3	3	1^x	2	1^x	18^x	4^x	2^x	3^x	4	5	4^x	4^x	3	31^x
19	2	3	2	1	2^x	2	2	3	17^x	2^x	1^x	1^x	3	1^x	1	1^x	1^x	14	3	3^x	3^x	2^x	3	4	2^x	2^x	24^x
20	2	3^x	3	2	2^x	2^x	2^x	2	20	1	1^x	2^x	2^x	2^x	2	1^x	1^x	15	3	3	2^x	2	2	2^x	3	2^x	20^x
21	1^x	1^x	1	2	2^x	1^x	1^x	0^x	12	1^x	1	3	4	4	4	3	3^x	24	1^x	1^x	3	3	3	1^x	1^x	1^x	16^x
22	0	0^x	2	2	2	1^x	2	1^x	11^x	2^x	3^x	3	2	2^x	2	1^x	1^x	18^x	2^x	3	4^x	5	3^x	2	2	1^x	24
23	1	3	3^x	3^x	3	3	2^x	3	22^x	2	2	3	2^x	2^x	2^x	2	2^x	19	1^x	2	0^x	0^x	2	0^x	1	1	9
24	2^x	2	2	3	4^x	4	2^x	4	24^x	1^x	2^x	3^x	3	3	3^x	3^x	2^x	23	1^x	0^x	1^x	0^x	0	0^x	1	0^x	6
25	4^x	3^x	3^x	4^x	4^x	3	3^x	3^x	30^x	3	2^x	2^x	2^x	2^x	3	2	2	20	1	0	0	0^x	1^x	0^x	0^x	0	4
26	3	2^x	3	3^x	4^x	4^x	3	4	28	3	3	4	3^x	3	3	2^x	2^x	24^x	0^x	0	0	0	0	0	0^x	0	1
27	4	3^x	4	4	4	4	3	2^x	29	2^x	2^x	1	2^x	2	1^x	1	1^x	14^x	0^x	0	0	0	0	0^x	0^x	1^x	3
28	3	3	3	3^x	4	3^x	3	1^x	24^x	0^x	1^x	1^x	2	2	1^x	1^x	0^x	11	1^x	0^x	0	1^x	2^x	2	1^x	1^x	11
29	2	1^x	2^x	1	0^x	2^x	2	1^x	13^x	1^x	1^x	1^x	0^x	0^x	1^x	1	2	10	0^x	0^x	1^x	2	0^x	0	0	1	6
30	2^x	0^x	0^x	0^x	0	0	0^x	0	4^x	2	0	1	1	0^x	0^x	0^x	0	5^x	1	0^x	0	0	1	2	1^x	1^x	7^x
31	1	2	0	0	0	0	0	0^x	3^x										1	0	1	0^x	0^x	0	0	0^x	3^x

Table 2--World-wide magnetic three-hour-range indices, K_W, 1938-39--continued

Day	January 1939									February 1939									March 1939								
	Values K_W								Sum	Values K_W								Sum	Values K_W								Sum
1	0x	1	1x	0x	1	0x	0	0	5	2	0x	1	1x	2x	3	4	3x	18	2	2	3	3x	3x	4	3	4	25
2	1	1	1x	2	1x	1	1x	1	10x	4x	3	2x	1x	2	2x	3x	3x	23	5	4x	3	3x	3	1x	1x	2	24
3	1x	1	1x	0x	1	1	0x	0	7	2	2x	2	2	1x	1x	2x	3	17	2	3x	3	3x	3x	3x	2x	3x	25
4	0	0x	0x	0	0	0x	1x	1x	4x	2x	2	2	3	2	0x	1	0x	13x	4x	4	3x	3	3x	3	3	3x	28
5	1	3	1x	2	2x	2	2	2x	16x	1	1x	2	2x	2	2	3x	3	17x	2x	1x	2	3	2x	2x	2x	3	19x
6	1x	1	0x	1x	1x	2	2	2	12	3	4	4	5x	5	4x	4	4x	34x	2x	2x	3	3	3	3	2x	3	22x
7	2	1x	1	2x	1x	2	2	2x	15	3x	3x	2x	3x	3	2	3	1x	22x	2x	2	0x	1	1x	1	1	1x	11
8	3	3	1	1x	1x	1x	2x	1x	15x	1x	0x	0	0x	1x	1	1x	2x	9	2x	3x	3	3	1x	1x	2x	1x	19
9	1x	2	3x	2	2	2	2	2x	17x	1	1	0x	3	2	2	3	2x	15	2	3x	4	3	2x	2x	2x	1x	21x
10	2	2x	1x	2x	3	2	2	2	17x	3	3	1x	1x	2x	3x	2x	2	19x	3	2	1	1x	2x	2x	2	3	17x
11	1x	1	1x	1x	1x	1x	2	2x	13	4x	4	3	2x	1x	0	0x	0	16	1	1	3	3	2x	3x	2	3	19
12	2	1x	1x	0x	2	1x	1	1	11	0x	0	0	0	0x	1	0	0	2	2x	2x	2x	2x	2	3	3	3	21
13	1	0x	0	1	1x	1x	0	0x	6	0	0	0	0	0x	1	2x	2x	6x	1x	0x	2	3	2	1	0	0x	10x
14	3	2x	1	2x	2x	2x	1	3	18	2	1x	2x	1	2	2	2x	1x	15	0x	1x	1x	3x	2x	2x	1x	1x	15
15	0x	2x	2	2	1x	1x	1	0x	11x	3	2x	2x	2	3	2x	2	2	19x	0x	2	3	3	2x	4	3	2	20
16	1	0	0x	2	1	1x	2x	2	10x	2x	3x	3	2	3	3	2	2x	21x	3x	3x	3	4	3x	3	3	3	26x
17	4	3	2	2x	2x	2	2x	2	20x	1x	2x	3	3	3x	3	3	2	21x	3	3	3x	0x	2	2x	2x	1	18
18	2x	2x	2x	0x	0x	1	0	1x	11	3	1	3	2	2	2x	2	2x	18	1x	1	1x	2	1	0x	0	0	7x
19	1	1x	1x	0x	0x	0x	1x	2x	9x	2x	2x	2x	2x	3	1x	2x	1x	18x	0x	0x	0x	0	0	0x	2x	1x	6
20	2x	2x	3	2	0x	1x	2x	2	16x	2	2x	0	0	1	2x	1	0x	9x	3x	3	1	1x	1	2x	0x	0x	13x
21	2x	1x	1x	1x	3	3	3x	1x	18	1	2	0	0x	0	0	0	0	3x	0x	2	4	4x	3	3	4x	2	23x
22	1	1x	2	1	2	1x	3x	3x	16	0	0	1x	1	1	1	1x	0x	6x	3	3x	3x	4	3x	4	3	3	27x
23	2x	3	2x	2x	2x	1x	1x	0x	16x	2x	1	0x	0x	2	1	1x	2	11	4	3	2	3	3	3x	3	3x	25
24	0x	3	2x	1	1x	0	0x	1x	10x	2x	3	2x	2	3	5	6	6x	30x	2	2x	2x	2	3	2	1x	2x	18
25	2	2x	2	1x	0x	0	0x	1	10	7	5	6	5x	5	4	3x	3x	39x	1x	2	2	1x	1x	0x	1	2	12
26	0x	0	0	0x	0x	0	0	0	1x	1x	1	0x	0x	0x	1	1	2x	8x	3	2x	2x	2x	1x	2	3	3	20
27	0	0	0	0x	0	0	0	0	0x	0	0x	0x	0x	2	1	0x	0	5	4	3x	2	3	1x	2x	5	4x	26
28	0	0x	0	0	0x	2	2	1x	6x	1	2	2	1x	2	3	2x	2x	16x	3x	3x	3	3	4x	5x	5	5x	33x
29	2x	1	0	0x	0	0	0	0x	4x										4x	5	4x	5	4x	4x	4	4x	36x
30	0x	1	1	1	0x	0x	1	1	6x										4	3x	3	3	2x	3x	4	4	27x
31	0x	1x	0x	2x	1x	0x	0x	0x	8										4	3x	2x	3	2x	3	2x	3x	24x

Day	April 1939									May 1939									June 1939								
	Values K_W								Sum	Values K_W								Sum	Values K_W								Sum
1	3x	3x	3	2x	3	3x	3	3x	25x	2	0x	3	4x	5x	4	5	5	29x	2	1x	1x	1x	3x	4	3x	2	19x
2	3	3x	2	2x	2x	3	2x	3x	22x	5	4x	6	4	3x	3x	3x	3x	33x	3x	3x	3	3	3	3x	3	3	25x
3	2	2x	3x	3	2x	2x	3	2x	21x	3x	2x	3x	3x	2x	2x	3	2x	23x	2x	2x	3	3x	3	3	2x	2	22
4	3	2x	2x	1x	1x	2	4x	3x	21	2	2	1x	2x	0x	2	1x	1	13	3	3	3	2x	3x	3	2	2	22
5	3x	3x	3	2x	3x	2	2	1x	21x	2	2x	2x	2x	2	2x	5x	4	23x	2x	2x	3	2x	2x	2x	1x	2	19
6	0x	2x	3	1x	1x	1	1	0x	11x	3x	2x	3	3x	4x	4x	4	4x	30	1x	2	1x	1x	1	1x	1x	1x	12
7	1	1	1	1	1	2	1	0x	8x	5x	4x	4x	4x	3x	3	3	3x	32	1x	1	1x	1x	1	1x	1	0x	9x
8	1	2x	2	1x	2	2	4	3	18	5	3x	4	4	4	2x	3x	3	29x	1x	1x	1	1	1x	1	1x	0x	9x
9	2x	2	2	2	3	3	3	3	20x	3x	4x	3	3x	3	3	2	2	24x	0x	1	1	1	1	0	0	1x	6
10	4x	3x	3x	3	4	3	4x	4x	30x	2	1x	1x	1x	1x	3	1x	1x	14	2x	2x	1x	2	2x	1	0x	1	13x
11	4	2x	3	4x	3	4	3x	3x	28	1x	1x	1	3	2	0x	1	0	10x	1	1	1x	2x	1x	1	1x	1x	11x
12	3	3x	3x	2x	3	1	2	2x	21	1	1x	2	1x	2	1	1	1x	11x	1x	1x	2	1x	1	0x	0	1x	9x
13	2	1x	3	2	2x	2	2	1	16	0x	1x	2	1x	2x	2	1	2	13	2x	2x	2	2	2	3	3x	3x	21
14	2	2	1x	2	2x	2x	2x	2	17	1	1	1x	0x	1	1x	2	1x	10	5	4x	5	6	3x	3x	3	3x	34
15	1	1x	1x	1x	1x	1	1	0x	9x	2	2	3	2x	2x	2	2	2	18	2x	2x	2	2	2x	2x	2	2x	18x
16	0x	0x	1x	0	0	0	0	3	5x	4	4	4	3x	2	1x	2	1x	22x	3x	3x	5	5x	3	2x	2	1x	26x
17	5	6x	7x	6	6x	6x	4x	5	47x	2	1x	2	2	1x	2x	3x	3	18	0x	0x	0x	0x	0x	0x	2	2x	7x
18	2	2	4x	3x	4x	4x	4x	4	29x	2x	2x	1x	2	2x	2x	1	2x	17	3	3x	3	3	3	2x	3	3	24
19	3x	3x	3x	3	4x	4x	4x	3x	30x	2x	3x	3x	1	0x	1x	2x	2x	17x	3	3x	3x	2x	3	3	2x	3x	24x
20	4	3	3x	3	3	3x	2x	2x	25	3x	4	3x	3	2	2	1x	2	21x	4	3	2x	2x	3	2	2	2	21
21	3	2x	3	3	3	4	3x	2x	24x	2	1x	2	2x	3	3x	4	3x	22	3x	3	3x	3	2x	2x	4	2x	24x
22	4	2x	0x	1	3	3x	3x	2x	20x	4	3x	4	4	2x	3	2x	4	27x	2x	3	3	2x	1x	2	2	2	18x
23	3	5x	6x	5x	5	5x	4x	3x	39	3	3x	4	3	2x	3x	4	4x	28	3	3	2x	3	2x	2	2x	2	20x
24	3	2	1x	2x	1	6	8	6	30	4x	3x	2x	2	2x	3	4	4	26	3	2x	2	1x	2	1x	2	2	16x
25	6x	4x	4	4	4x	4	3x	3x	34x	3x	3x	2x	3	2x	4	4	3x	26x	1x	1x	1x	0x	1x	1	1	1x	10
26	3x	2	0x	0	1	1x	0	0x	9	3x	3	3	2x	2x	3x	2x	2	22x	2	2x	2x	2x	1x	1x	4	3x	20
27	0x	0	1x	1	0x	1x	0	4x	9x	2x	2x	1x	2	1x	1	3	3x	17x	2x	3	3x	4	3	2x	1x	2	22
28	3x	3x	2x	2	2x	2	2	2x	20x	4x	3x	3x	3	2	1x	2	3x	23x	1	2	1x	2x	3	3x	3x	4	21
29	1x	3	2x	3	2x	2x	2x	2x	20	4	4	5	3x	4	3x	3x	2x	30	3	4x	3x	3	3x	4	2	2	25x
30	1x	0	0x	0x	2	2	3	1	10x	1x	1	1x	2x	1x	1	0x	1	10x	3	2x	2x	3x	2x	2	2	3	21
31										2	2	2	1	0	0	1x	2	10x									

Table 2--World-wide magnetic three-hour-range indices, K_W, 1938-1939--concluded

Day	July 1939 Values K_W								Sum	August 1939 Values K_W								Sum	September 1939 Values K_W								Sum
1	2	1^x	3	3^x	2^x	2	2	2	18^x	2	2^x	1	1	1	0^x	1	0^x	9^x	0	0^x	0^x	0^x	0^x	1	0^x	0	3^x
2	2	2^x	3	2^x	2^x	2	2	2	18^x	0	0^x	1	0	0	0	0	0	1^x	1	1^x	1	1	1^x	2	2	4^x	14^x
3	3	3	4	5	5^x	5	4^x	3	33	0	0	0	0	0^x	0	0^x	0^x	1^x	6	5	4	4^x	2^x	3	3	4	32
4	2^x	2^x	2^x	2	4	4^x	5^x	5^x	29	0	1	0	1	1^x	1	0^x	1	6	2^x	2	0^x	1^x	1^x	1	0^x	0	9^x
5	5	5	5^x	6	5^x	6^x	6	3^x	43	0^x	1	0^x	1	0^x	1	1	1^x	7	0	1	0^x	0	0	0^x	1	1^x	4^x
6	4	4	2^x	3	0^x	0^x	0	1	15^x	0^x	0^x	0^x	0^x	0	0^x	0^x	0^x	3^x	2	1^x	2	1^x	0^x	1	3	2^x	14
7	1	0	0	0	0^x	0^x	1	0^x	3^x	1	0	0^x	1	1	1	0^x	0	5	2^x	2	1^x	1^x	1^x	1	1	1^x	12^x
8	1	0^x	0	0^x	0^x	1^x	2^x	1^x	8	1	0	0	0^x	0	1^x	2^x	0^x	6	1	1^x	1	2^x	0^x	1	0^x	1^x	9^x
9	2	0	0	0^x	0^x	0^x	0	0	3^x	0	0^x	0^x	1	0	0	0^x	0^x	3	3^x	3^x	4^x	3^x	3^x	3	3	3^x	28
10	2	1	1	0	0^x	0^x	1	0	6	0	1^x	1^x	4^x	2^x	2^x	2^x	2^x	17^x	3	3^x	3	1^x	3^x	3	3	1^x	22
11	0	0^x	0^x	2^x	4	3	4	1^x	16	1^x	1^x	1	0	2	3	2^x	4^x	16	3	2^x	2^x	0^x	1^x	1^x	1	1	13^x
12	0^x	1	1	2^x	3^x	4	3	2	17^x	5^x	7	6^x	5	4	3^x	3^x	4^x	39^x	3^x	2^x	3	2	2	2	2	3	20
13	1^x	1^x	1^x	0^x	1	0^x	2^x	1^x	10^x	5	4^x	3	3	2^x	3^x	3	2^x	27	1^x	0^x	0	2	1^x	1^x	0^x	2	9^x
14	2	2^x	4	4^x	4	4	2^x	3^x	27	2^x	3	2^x	2	1^x	1	1	0^x	14	3	2	1	2^x	2^x	2	1^x	2	16^x
15	3	2^x	3	2^x	2^x	2	2	2	19^x	0^x	0^x	1	0^x	0^x	2^x	1	1^x	8	1^x	1	0^x	1	1	1	1	2^x	9^x
16	2^x	2^x	3	3^x	3	3^x	4^x	3	25^x	1	2	2^x	3^x	5	6^x	4^x	4	29	2	1	0^x	1	2	1^x	1^x	1^x	11
17	3^x	3	4	2^x	2^x	2^x	2	3	23	4	4	3	2^x	2^x	2^x	2	1	21^x	2	4^x	3^x	3	4	5	5^x	4	31^x
18	2^x	2^x	2	2	2	3	2^x	1^x	18	1^x	1	0	1	1	1^x	1^x	1^x	9	3	2	1^x	2^x	1^x	1^x	0^x	0	12^x
19	2^x	2	2^x	2	1^x	1^x	2	4^x	18^x	1	1	2^x	2	2^x	3^x	1^x	1	15	2	3	3^x	4	4	4^x	3^x	4	28^x
20	3^x	4^x	4^x	4^x	5	4	3^x	3^x	33	1^x	2	2	1	2	1^x	2	1^x	13^x	3^x	4^x	4^x	4	3^x	3	2^x	1^x	27
21	2^x	2^x	0	5	6	4	2	3	25	1^x	1	0^x	2	2	1^x	1^x	3	13	2^x	2^x	3	2	2	2	2	2	18
22	3^x	4	2^x	3^x	3	3	2	2^x	24	6	6	4	5^x	6^x	6	6	6	46	2	2^x	2^x	3	2	3	1^x	2	18^x
23	3^x	2^x	2^x	2	1^x	2	1^x	0^x	16	6	5^x	5	6	5	3^x	3	2^x	36^x	1	0	1	1	0^x	0^x	1	2	7
24	2	1^x	2^x	1	3	2	2^x	2	16^x	3	1^x	3	3	3	2^x	1^x	1^x	19	1	2^x	1^x	2	1^x	0^x	1	0^x	10^x
25	2^x	3^x	4	2^x	1^x	1^x	1^x	0^x	17^x	2^x	2^x	1^x	2	1	1^x	1^x	1^x	14	0^x	1^x	2	3	2	2^x	2	3	16^x
26	1	4	5^x	4	3^x	3^x	3^x	3^x	28^x	1	1	1	2^x	2	1	1^x	1	11	4	3^x	2^x	3	2	2	3	2	22
27	2^x	2^x	3	2	2^x	3	2	3	20^x	2	1^x	1	1^x	2	1^x	2	2	13^x	1	1	0^x	0^x	0	1	2^x	1^x	8
28	1^x	1^x	2^x	2	1^x	2	2	2	15	0^x	0^x	0^x	2^x	1^x	1	1	1	8^x	1^x	0^x	1	0^x	1	0^x	1	0^x	6^x
29	1	1^x	1^x	2	1^x	1^x	2	0^x	11^x	2^x	1	0	1^x	0^x	0	0^x	0	6	0^x	0^x	1	1	0	1	0^x	0^x	5
30	1	2^x	1^x	1	0	1^x	0^x	0	8	0	0^x	0^x	1^x	2	2^x	2^x	1^x	11	0^x	0^x	1	2^x	1	1	3	3	12^x
31	1	1^x	2^x	0^x	1	1	2	1^x	11	0	0	0	0^x	0^x	1^x	2	1	5^x									

Day	October 1939 Values K_W								Sum	November 1939 Values K_W								Sum	December 1939 Values K_W								Sum
1	2^x	1^x	0^x	0^x	2	2^x	2	1^x	13	2	0^x	2	2	2	2	2^x	0^x	13^x	1^x	3	3	2	1^x	1^x	2	1^x	16
2	0^x	1	2	0^x	1^x	2	2	2^x	12	0^x	2^x	2	1^x	1^x	0^x	1	0^x	10	1^x	1	2^x	1	0^x	1^x	2	2	12
3	2^x	2	3	4	5	4^x	5^x	4^x	31	1^x	1	1	2	2	1^x	1^x	2	12^x	0^x	1^x	1^x	1	0^x	1	1^x	3	10^x
4	6	5^x	3	2	4	2^x	2^x	2	27^x	2	0^x	1^x	1^x	1	0^x	1	1	9	2^x	1	1^x	0	0^x	0	0^x	0^x	6^x
5	2	2^x	2	3^x	3	2	3^x	2	20^x	1	0^x	1	2^x	1^x	1^x	1	0^x	9^x	1	0^x	0^x	0^x	2	3	2^x	2^x	12^x
6	3^x	5^x	4	3^x	2^x	3	3^x	2^x	28	0^x	1	1	1^x	1	1^x	2	2	10^x	3	1^x	1^x	1^x	1^x	1^x	5	4^x	20
7	1^x	0^x	0^x	1^x	2^x	3	3	2^x	15	2	1	1^x	1^x	1	2	1^x	1	11^x	5^x	5	5	4	4^x	4	3	3^x	34^x
8	2^x	2	1^x	0	2	1^x	2^x	2	14	0^x	0^x	1	1	2	0^x	1	0^x	7	3	4	4	3	3	4	3^x	2^x	27
9	2^x	2	5^x	3	4^x	2^x	2	0^x	22^x	0^x	2	1^x	1	0^x	1	0^x	0^x	7^x	3^x	2	3	3	3^x	3	3	1	22
10	1	1	1	1^x	2	1^x	0^x	2	10^x	0^x	1	0^x	0^x	0^x	1	0^x	0	4^x	1^x	2	1^x	2	2^x	2	1^x	2	15
11	2	3	1	1^x	2^x	1	3	3	17	1	1^x	0	0^x	0	1	2	2	8	2^x	1^x	2^x	2	2	1^x	1	1	14
12	2	1	0	0	0	0^x	0^x	0^x	4^x	3	0^x	0^x	3	3	2	1^x	2	15^x	2^x	1^x	1^x	1	1	2^x	1^x	3	14^x
13	4^x	5	5^x	3^x	3^x	5	6^x	6	39^x	3	4	4^x	5^x	4^x	3^x	3^x	4	32^x	1	2	1	1	1^x	1^x	0	0	8
14	4^x	4^x	6	5^x	5^x	4^x	3^x	3	37	4^x	3^x	2^x	2^x	2^x	2^x	2	3	23	1	0	1^x	0^x	0^x	1	0^x	1	6
15	5^x	6	5^x	3	3	4	3	2	32	2	2	2^x	1	1^x	2^x	2	0^x	14	1^x	2^x	2	1^x	1^x	2^x	1^x	2	15
16	3	3	3^x	3	4	5	3^x	4	29	1	0^x	1	0^x	1	1^x	0^x	0^x	6^x	0^x	1	0^x	1	1	2^x	1^x	4	12
17	3	4^x	3^x	3^x	3	4^x	4	3	29	0^x	0	1	1^x	0^x	1	2	0^x	7	2^x	1	1^x	2	1	1	0^x	1	10^x
18	3^x	3	3^x	3^x	3^x	4	3	3	27	0^x	1^x	1^x	1^x	0	0^x	0^x	0^x	6^x	1	0^x	0^x	0^x	0	0	0	0	2^x
19	2^x	3^x	3	4	2^x	2^x	2^x	1^x	22	0^x	0^x	0	1^x	2^x	3	2^x	2^x	13	0	1	0^x	0	0	0	0	0	1^x
20	1^x	1	2	1^x	0^x	0^x	0^x	0	7^x	3	2^x	1^x	0^x	0	0^x	1^x	1^x	11	0	0	0	0	1	1^x	1^x	1	5
21	0^x	2	3	2	3	2	3	3^x	19	1	1	2	1^x	1^x	1	1	0	9	1^x	3	4	4	3^x	3	3	3	25
22	1^x	1	1^x	0^x	1	1	2^x	2	11	0	0^x	0	0	0	0	0	0^x	1	3^x	3^x	3	3	4	3^x	2^x	2^x	25^x
23	0^x	1^x	2	2^x	3^x	4	2	2	18	0	1	1^x	1	0^x	0^x	1	1	6^x	1^x	3	3	2^x	1^x	2	1	1^x	16
24	2^x	1^x	1^x	1	0^x	1	1	0^x	9^x	0^x	1^x	0^x	0^x	2^x	2	2^x	3	13	2^x	2^x	3	2	2	1^x	2	2	17^x
25	1^x	1^x	1^x	1	2^x	0^x	1	0	9^x	3	3^x	3^x	2^x	2^x	3	3^x	4	25^x	2^x	1^x	1	1	2	1^x	1^x	1^x	12^x
26	1	0^x	2	1^x	0^x	0^x	2^x	1^x	10	3	3^x	3	3	2^x	2	2^x	1^x	21	1	2	2	1	1	0	1	1	9
27	1	0^x	0^x	0^x	1^x	2^x	0^x	0^x	7^x	1	2^x	1^x	2	1	1	2	0^x	11^x	2	3	3	3	2	2^x	3	2^x	21
28	0	1	2^x	3	2^x	1^x	1	2	13^x	0^x	2^x	1^x	2	2	1	1	0	10^x	1^x	1^x	2	2^x	2	2	2^x	2	16
29	2^x	2^x	1^x	1^x	1^x	1^x	1^x	1	13^x	0^x	0^x	1	1^x	1	1^x	1	1^x	8^x	2^x	2^x	1^x	2^x	2	2^x	2^x	1^x	17^x
30	2^x	1^x	1	1	2	1^x	1^x	2	13	1	2	1^x	1	1	1^x	1^x	1^x	11	2	1^x	1	1^x	1^x	2	1	1^x	12
31	2	1^x	1^x	1	2	1^x	1	1	11^x										0^x	1^x	0^x	0^x	0^x	0	0	0	3^x

Figures 1 and 2—Graphical tables for the world-wide indices K_w, arranged in "solar rotations" of 27 days for the study of recurrence-tendencies are shown in Figures 1 and 2. Intervals with $K_w > 5$ are emphasized as shown in the key at the top of Figure 1.

Table 3—World-wide daily indices B, given to half-units, and derived from the indices K_w as explained in section (18) of our former paper are given in Table 3. For the first half of 1938, this new Table

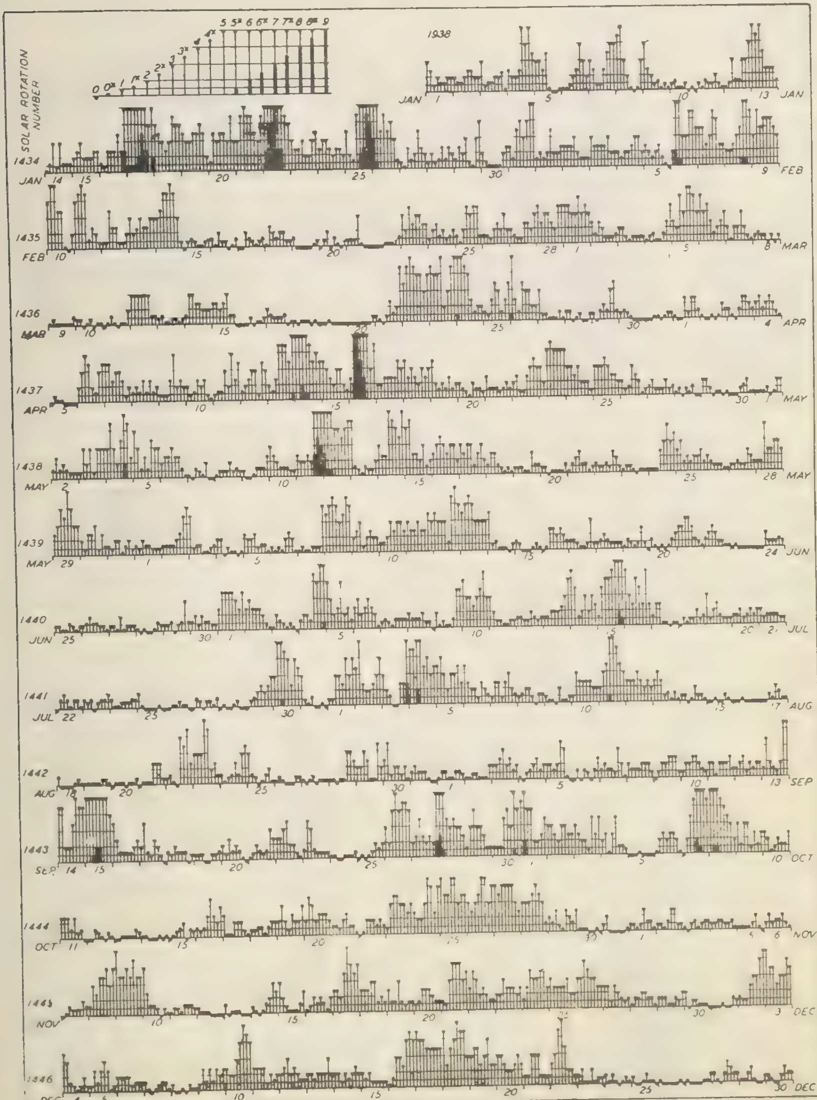


FIG. 1—WORLD-WIDE MAGNETIC THREE-HOUR-RANGE INDICES K_w, JANUARY 1 TO DECEMBER 30, 1938

supersedes the previous Tables for $2B$. The eight B-indices given for each date refer to 24-hour intervals beginning at 00^h, 03^h, 06^h, . . . 21^h GMT on that date. For instance, B-indices for Greenwich days appear in the first of the eight vertical columns; B-indices for local days on the meridian 135° west, where local midnight occurs at 09^h GMT, appear in the fourth column; B-indices for local days on the meridian 135° east, where local midnight occurs at 15^h GMT on the previous Greenwich

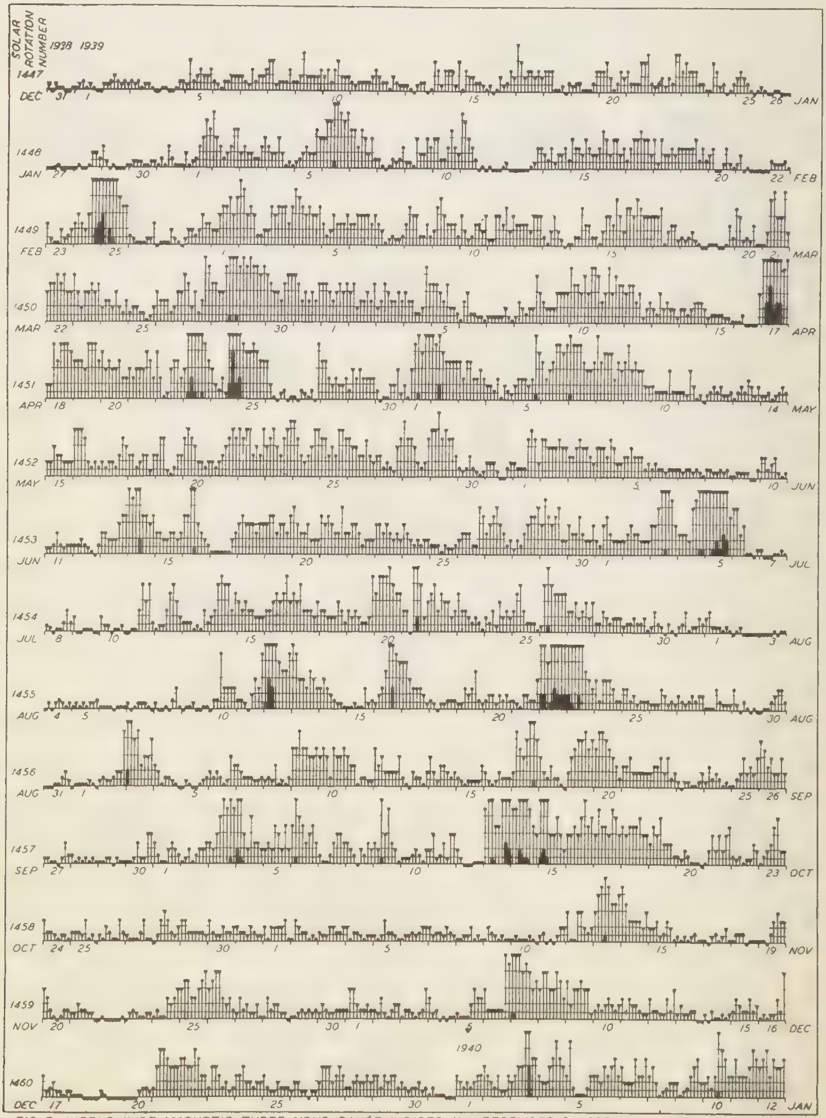


FIG. 2—WORLD-WIDE MAGNETIC THREE-HOUR-RANGE INDICES K_W, DECEMBER 31, 1938 TO JANUARY 12, 1940

Table 3--World-wide daily magnetic indices B, 1938-39

Day	January 1938	February 1938	March 1938	April 1938
1	2 2 1x 2 2 2 2 2	2x 2x 2x 2x 2x 2x 2x 2x	3x 3 3 3 3 2x 2x 2	1x 1x 1x 1x 1x 1 1 0x
2	2 2 2 2 2 2 2 2	2 2x 2x 2x 2 2x 2x 2x	1x 1x 1x 1x 1x 1x 1x 1x	0x 1 1 1 1 1x 1x 1x
3	2 2 2 2 2 3 3 3x	2x 2x 2x 2x 2 2 2 2x	1x 1 1 1 1 1 1 1x	1x 1x 2 2 2 2 2 2
4	3x 3x 4 4 4 3x 3 2x	2x 2x 2x 2x 2x 2x 2 2	2 2 2 2x 2x 3 3x 3x	2 1x 1x 1x 1 1 0x 0x
5	2 2 1x 1x 0x 1 2 2x	2 1x 3 3x 3x 3x 4 4	3x 4 4 4 3x 3x 3 3	0x 0x 1 2 2x 2x 2x 2x
6	2x 2x 2x 2x 2x 2x 2x 2x	4x 4x 4 3x 3x 4 3x 3x	3 2x 2x 2 2 2x 2x 2	3 3 3 3 3 3 3 3
7	3 3 3x 3x 4 3x 3x 3	3x 3 3 3 3 3 3x 4	2 2 2 1x 1x 1 1 1	3 2x 2x 2 2 2 2 2
8	3 3 2x 2x 2x 2x 2x 2x	4 4 4x 4x 4x 4x 4 4	1 1 0x 0x 0x 0x 0x 0x	2 2 2 1x 1x 2x 2 2x
9	2 1x 1 1 1 1 1 0x	3x 4 4 4 4 4 4 3x	0x 1 1 0x 0x 1 0x 0x	2x 2x 2x 2x 2x 2 2 2
10	0x 0x 0x 0x 0x 0x 1 1	3x 3x 3x 3x 3x 3x 3x 3x	0x 0x 0x 0x 0x 0x 0x 0x	2 1x 1x 1x 2 2 2x 2x
11	1 1 1 1x 1x 1x 2 2	3x 3x 3 2x 2 2 2 2	1 1x 2 2 2x 2x 3 3	2x 2x 2x 3 3 3 2x 2x
12	2x 3 3x 4 4 4 4 4	2 2x 2x 2 2x 2x 2x 2x	3 2x 2x 2 2 1x 1 1	2x 2x 2x 2x 3 3 3x 3x
13	3x 3x 3 2x 2 2 2 2	2x 2x 3 3 3x 4 4 4	1 1 1x 2 2 2 2 2x	4 4 4x 5 5 5 5 5
14	2 2 2 2 2x 2 2 2x	4 4 3x 3x 3 2x 1x 1	2x 2x 2x 2x 2x 2x 2x 2x	5 4x 4x 4 3x 3 3 3
15	2x 2x 2 2 2 2 2x 2x	1 1 1 1 1 1 1 1	2 2 1x 1x 1x 0x 0x 0x	2x 2x 3x 6 6x 6x 6x 6x
16	3x 4 4x 5 5 5x 6 6	1 1 1 1 1 1 1 1	0x 0x 1 1 1 1 1x 1	7 7 6x 5 4 3x 3 3
17	6 6 6 5x 5x 4x 4 4	1 1 1x 1x 1x 1x 1x 1x	1 1 0x 0x 0x 0x 0x 0x	2x 3 3 3 3 3 3 3
18	3x 3x 3x 3x 3x 3x 3x 3x	1x 2 1x 1x 1 1 0x 0x	0x 0x 0x 0x 0 0 0 0	3 3 3 2x 2x 2x 2x 2x
19	3x 3 3 3 3 3 3 3	0x 0 0x 0x 0x 1 1 1	0 0 0 0 0 0 0 0	2 2 2 2 1x 1x 1x 1x
20	3x 3x 3x 4 4 4 4 4	1 1 1 1 1x 1x 1x 1x	0 0x 0x 0x 0x 1 1 1x	1x 1x 1x 1x 1x 1x 1x 1x
21	4 4x 5 5x 7 7 7 7	1 1 1 1 0 0 0 0x	2 2x 3 3x 4 4 4 4	1x 1x 1x 1x 1x 2 2 2x
22	7 7 7 6x 4x 4 3 3	0x 1 1x 2 2 2x 2x 2x	4 4x 4 4 4 4 4 4	2x 2x 2x 3 3x 3x 3x 3x
23	3 2x 3 3 3 3 3 2x	3 2x 2x 2x 2x 2 2 2	4 4x 4x 4x 4x 4x 4x 4	4 4 4 3x 3x 3x 3 3
24	2x 2x 2x 2x 3 3x 4x 5x	2 2 1x 1x 2 2 2x 2x	4 3x 3 2x 2 2x 2x 2x	2x 2x 2x 2x 2x 2x 3 3
25	6 6x 6x 6x 6x 6x 6x 5x	2x 2x 2x 2x 2x 2x 2 2	2x 3x 3x 3x 3x 3x 3x 3x	3 3 2x 2x 2x 2 2 2
26	4x 3x 3 3 2x 2x 2 2	2 2 2 2 2 2 2 2	3x 2x 2x 2x 2x 2 1x 1x	2 2 2 2 1x 1x 1x 1x
27	2 2 2x 2 2 2 2 2	2 2x 2x 2x 3 3 3 3	1x 1 1 1 1 1 1 0x	1x 1x 1 1 1 1 1 1
28	2 2 2 2 2x 2 2 2	3 3 3 3 3 3x 3x 3x	0x 0x 0x 0x 1 1 1x 2	0x 1 1 1 1 1 1 1
29	2x 2x 2x 2x 2 2 2 2		2 2 2 2 2 2 1x 0x	1 0x 0x 0 0x 0x 0x 1
30	1x 1x 1x 2 2x 2x 3 3x		0x 0x 0 0 0 0 0 0x	1 1 1 1 1 1 0x 1
31	4 4 4 3x 3x 3x 3x 3		0x 0x 0x 0x 1 1 1x 1x	

Day	May 1938	June 1938	July 1938	August 1938
1	1 1 1x 1x 1x 2 2 1x	1x 1x 1x 1x 1x 1x 1x 2	3 3 3 3 3 3 2x 2x	3 3 3x 3x 3x 3x 3x 3x
2	1x 1x 1x 2 2 2 2 2x	2x 3 2x 2x 2x 2x 2x 2x	2 2 2 1x 1x 1 1 1	3x 3x 3 2x 2x 2x 2x 2x
3	2x 3 3 3 3 3 4 4	1x 1x 1x 1x 1 1 1 1	1 1 1 1 1x 2 2x 3	3x 3x 4 4x 4x 5 5 5
4	4 4 4 4 4 3x 3 3	1 1 1 1x 1x 1x 1x 2	4 4 4 4 4 4 4 3x	4x 4x 4x 4 3x 3x 3 3x
5	3 2x 2x 2x 2x 3 2x 2x	2 1x 1x 1x 1 1 1x 1x	3 2x 2x 2x 2x 2x 2x 2x	3 3 3 3 3 2x 2x 2x
6	2x 2 2 2 1x 1 1 1	1x 1x 1x 1x 1x 1x 1 1	2x 2x 2 2 2 1x 1x 1	2x 2 2 2 2 2 2 2
7	1 1 1 1 1 1 1 1	2 2 2x 3 3x 3x 3x 4	1x 1x 1x 1x 1x 1x 1x 1x	2 2 2 2 2 2 1x 1x
8	1 1x 1 1 1 1 1 1	4 4 3x 3x 3 3 3 2x	1x 1x 1x 1x 1 1 1 1x	1x 1x 1x 1 1 1 1 1
9	1 1x 2 2 2 2 2 2	2 2 2 2 2 2 2x 2x	2 2x 2x 3 3 3 3x 3x	1 1 1x 1x 2 2 2 2x
10	2 2 1x 1x 2 2 3x 4x	2x 2x 2x 3 3 3 2x 3	3x 3x 3 3 3 3 2x 2	2x 2x 2x 2x 3 3x 4 4
11	5x 5x 6 6 6 6 6 5x	3 3 3 3 3 3 3x 3x	1x 1 1 1 1 1x 1x 1x	4 4 4 4 3x 3 2x 2x
12	5 4x 4 3x 3x 3 3 2x	3x 3x 4 4 4 4 4 3x	1x 1x 1x 1x 1x 1x 2 2	2x 2x 2x 2x 2x 2 2 2
13	2 1x 2 2 3 3 3x 3x	3x 3x 3x 3 2x 2x 2 2	2x 3 3 3 3 3 3 3	2 1x 1x 1 1 1 1 1
14	4 4 4x 4x 4 3x 3x 3x	1x 1 1 0x 0x 0x 0x 0x	3 2x 2x 3 3 3x 3x 4x	1 1 0x 1 0x 0x 0x 0x
15	3 3 2x 2x 2x 2x 2x 3	0x 0x 0x 1 1 1x 1x 2	4x 5 4x 4x 4x 4x 4x 4	0x 0x 0x 0x 0x 0x 0 0
16	3 3 3 3 3 2x 2x 2x	2 2 2 2 1x 1x 1x 1x	3x 3 3 3 3 2x 2x 1x	0 0 0 0 0 0x 0x 1
17	2x 2x 2x 2x 2 2 2 1x	1x 1x 1x 1x 1x 1x 1x 1x	1x 1 1 0x 0x 0x 1 1	1 1 1 1 1 0x 0x 0x
18	1x 1x 1x 1 1 1 1 1	1x 1x 1x 1 1 1 1x 1x	1 1x 1x 2 2 2 2 2	0x 0x 0x 0x 0x 0x 0x 0x
19	1x 1x 1x 1 1 1 1 0x	1 1x 1 1 1 1 0x 0x	2 1x 1x 1x 1x 1x 1x 1x	0x 0x 0x 0x 0x 0x 0x 0x
20	0x 0x 0x 1 1x 1x 1x 1x	1 1 1x 2 2 2x 2x 2x	1x 1x 1x 1x 1x 1x 1x 1x	0x 0x 0x 0x 0x 1 1x 1x
21	1x 1x 1x 1x 1 1 1x 1x	2x 2 2 2 2 1x 1x 1x	1x 1 1 1x 1x 1 1 1x	1x 1x 1x 1x 1x 2 2x 2x
22	1x 1x 1x 1x 1x 1x 1 0x	1x 1x 1 1 0x 0x 0 0	1 1x 1x 1 1 1 1 1	3 3 3 3 3x 4 3x 3x
23	0x 0x 0x 0x 1 1x 2 2x	0 0 0 0x 0x 0x 0x 1	1x 1x 1x 1 1x 1x 1 1	3x 3x 3 3 2x 1x 1x 2
24	2x 3 3 3 3 3 2x 2x	1 1 1x 1 1 1 1 1	1 1 1 1 1 1 1 0	2 2x 2x 2x 2x 2 2 2
25	2 2 2 2 2 2 1x 1x	1 1 1 1 1x 1x 1x 1x	0x 0 0 0 0 0x 0x 0x	1x 1 1 1 1 1 0x 0x
26	1 1 1 1 1 1 1x 1x	1x 1x 1x 1 1 1 1 1	0x 0x 0x 0x 0x 0x 0x 0x	0x 0x 0x 0x 0x 0x 0x 0x
27	1x 1x 1x 2 2x 2x 2x 2x	1 1 1 1 0x 0x 0x 0x	1 1 0x 0x 0x 0x 0x 0x	0x 0x 0x 0x 0x 0x 1 1x
28	2x 3 3 3 3 3x 3x 3x	0x 0x 0x 1 1 1 1 1x	0x 0x 0x 0x 1 1 1x 1x	2 2 2 2x 2x 2x 2x 2x
29	3x 3x 3x 3x 3 3 2x 2x	1x 1x 1x 1x 2 2 2 1x	2 2x 3 3x 4 4 4 4	2x 2x 2x 2x 2x 2x 2x 2
30	2 2 2 2 2 1x 1x 1x	1x 1x 2 2x 2x 3 3 3	4 4 4 3x 3 2x 2x 2	2 2 1x 1x 1x 1x 1x 1
31	1x 1x 1x 1x 1x 1x 1x 1x		1 0x 0x 1 1x 1x 2x 2x	1 1 1 1 0x 0x 0x 1

Table 3--World-wide daily magnetic indices B, 1938-39--continued

Day	September 1938							
1	1	1	1	1	1	1	1	0^x
2	1	1	1^x	1^x	2	2	2	2^x
3	2^x	2	2	2	1^x	1^x	1^x	1^x
4	1^x	2	2	2	2	2^x	2^x	2^x
5	2	2	2	2	2	1^x	0^x	0^x
6	1	1^x	1^x	1^x	1^x	1^x	2	2
7	2	2	2	2	2	2	1^x	1^x
8	1^x	1^x	1^x	1^x	1^x	1^x	2	2
9	2	2	2	2	2	2	2	2
10	2	2	2	2	2	1^x	1^x	2
11	2	2	2	2	2	2	2	2
12	2	2	2	2	2	2	2	2^x
13	3	3^x	3^x	3^x	3^x	3^x	4	4
14	4	4	4	4^x	5	5^x	5^x	5^x
15	5^x	5	5	4^x	4	3^x	3	2^x
16	2	2	2	2	2	2	2^x	2
17	2	2	1^x	1^x	1^x	1^x	1^x	1
18	1^x	1^x	1^x	1	1	0^x	0^x	1
19	1	1	1	1^x	1^x	1^x	1^x	1^x
20	1^x	1^x	1^x	1^x	1^x	1	1	1^x
21	2	2	2	2^x	2^x	2^x	2^x	2^x
22	2^x	2^x	2^x	2^x	2	2	2	2
23	2	2	1^x	1	0^x	0^x	0^x	0^x
24	0^x	0^x	0^x	0^x	0^x	0^x	1	1
25	1	1^x	2	2^x	3	3^x	3^x	4
26	4	4	4	4	3^x	3^x	3	3
27	3^x	4	4^x	4^x	4^x	4^x	4^x	4^x
28	4^x	3^x	3	3	3	3	3	3
29	2^x	2^x	2^x	2^x	2^x	2^x	2^x	3^x
30	3^x	4	4^x	4^x	4^x	4^x	4^x	4
31								

Day	October 1938							
1	4	4	3	3	2^x	3	3	3
2	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x
3	2^x	2^x	2^x	2^x	2^x	3	2^x	2^x
4	2	2	1^x	1^x	1^x	0^x	0^x	0
5	0	0	0^x	1	1	1^x	2	2
6	2	2	2	2	2^x	3^x	4	4^x
7	4^x	5	5	5	5	5	5	4^x
8	4^x	4	3^x	3^x	3	2^x	2^x	2^x
9	2^x	2^x	2^x	2	2	2	2	2
10	2	2	2	2	2	2	2	2
11	2	1^x	1^x	1	1	0^x	0^x	0^x
12	0^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x
13	0^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x
14	0^x	0	0	0^x	0^x	1	1	1
15	1	1	1^x	1^x	1^x	2	2	2
16	2^x	2^x	2^x	2^x	2^x	2	2	2
17	1^x	1^x	1^x	1^x	1^x	1	1	1^x
18	1^x	1^x	2	2	2	2	2	2
19	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x
20	2^x	2^x	2^x	2	2	2	2	1^x
21	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x
22	1^x	1^x	2	2^x	2^x	2^x	3	3
23	3	3	3	3	2^x	3	3	3
24	3^x	3^x	3^x	4	4	4	4	4
25	4	3^x	3^x	3^x	3^x	3^x	3^x	3^x
26	3^x	3^x	4	4	4	4	4	4
27	3^x	3^x	3^x	3^x	3^x	3^x	3	3
28	3	3	3	3	2^x	2	2	2
29	2	2	2	1^x	1^x	1^x	1	1
30	0^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x
31	0^x	0^x	0^x	0^x	0^x	1	1	1^x

Day	November 1938							
1	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x
2	1^x	1^x	1^x	1^x	1^x	1	1	1
3	1	1	1	1	1	1^x	1^x	1^x
4	1	1	1	1	1	1	1	1
5	1	1	1	1	1^x	1^x	1^x	1^x
6	1^x	1^x	1	1	1	1	1	1
7	1	1^x	1^x	2	2^x	2^x	3	3
8	3^x	3^x	3^x	4	4	4	4	4
9	4	4	3^x	3^x	3^x	3	2^x	2^x
10	2	1	1	1	0^x	1	1	1
11	1	1	1	1	1	1	0^x	0^x
12	0^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x
13	0^x	0^x	0^x	0^x	0^x	0^x	1	1^x
14	1^x	2	2	2	2	2	2	1^x
15	1^x	1^x	1	1^x	1^x	1^x	1^x	1^x
16	1^x	1^x	2	2	2^x	3	3	3^x
17	3^x	3^x	3^x	3^x	3^x	3	3	3
18	2^x	2^x	2^x	2	2	2	2	2
19	2	1^x	1^x	2	1^x	2	2	2
20	2	2	2	2	2^x	2^x	3	3
21	3^x	3^x	3^x	3^x	3^x	3	3	2^x
22	2^x	2^x	2	2	2	2	2^x	2^x
23	2^x	2^x	2^x	2^x	2^x	2^x	3	3
24	3	3	3	3	3	3	3	2^x
25	2^x	2^x	2^x	3	3	3	3	3
26	3	3	3	2^x	2^x	2^x	2	2
27	2	1^x	1^x	1^x	1^x	1^x	1^x	1^x
28	1^x	1^x	1^x	1^x	1^x	1	1	1
29	1^x	1^x	1^x	1	1^x	1^x	1	1
30	1	0^x	0^x	0^x	0^x	0	0	0^x
31								

Day	December 1938							
1	0^x	0^x	0^x	1	1	1^x	2	2^x
2	3	3^x	3^x	3^x	3^x	3^x	3^x	3^x
3	3^x	3^x	3^x	3	3	3	2^x	2^x
4	2	1^x	1^x	1^x	1^x	2	2	2
5	2	2	2	2	2	2	1^x	1^x
6	1^x	1^x	1^x	1^x	1	1	1	1
7	1	1	1	1	1	0^x	0^x	0^x
8	0^x	0^x	1	1	1^x	1^x	1^x	2
9	2	2	2	2	2^x	2^x	3	3^x
10	3^x	3^x	3^x	3^x	3^x	3^x	3	2^x
11	2	2	2	2	2	2^x	2^x	2^x
12	2	2	2	2	2	2	2	2
13	2	2	2	2	2	2	2	2
14	2	2	2	2	2	2	1^x	1^x
15	1^x	1	1	1^x	2	2	2^x	3
16	3	3^x	4	4	4	4	4	4
17	4	4	3^x	3^x	3^x	4	4	4
18	4	4	4	4	4	3^x	3^x	3
19	3	3	3	3	3	3	2^x	2^x
20	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x
21	2^x	2^x	2^x	3	3	3^x	3^x	3^x
22	3^x	3^x	3	3	2	1^x	1^x	1^x
23	1^x	1^x	1	1	1	1	1	1
24	1	0^x	0^x	0^x	0^x	0^x	0^x	0^x
25	0^x	0^x	0^x	0^x	0^x	0	0	0
26	0	0	0	0	0	0	0	0
27	0^x	0^x	0^x	0^x	1	1	1^x	1^x
28	1^x	1^x	1^x	1^x	1^x	1^x	1	1
29	1	1	1	0^x	0^x	0^x	1	1
30	1	1	1	1	1	1	1	0^x
31	0^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x

Day	January 1939							
1	0^x	0^x	0^x	0^x	1	1	1	1^x
2	1^x	1^x	1^x	1^x	1	1	1	1
3	1	0^x	0^x	0^x	0^x	0^x	0^x	0^x
4	0^x	0^x	1^x	1^x	1^x	2	2	2
5	2	2	2	2	2	1^x	1^x	1^x
6	1^x	1^x	1^x	1^x	2	2	2	2
7	2	2	2^x	2^x	2	2	2	2
8	2	2	1^x	2	2	2	2^x	2
9	2^x	2^x	2^x	2	2	2^x	2^x	2^x
10	2^x	2	2	2	2	1^x	1^x	1^x
11	1^x	1^x	2	2	1^x	2	2	1^x
12	1^x	1^x	1	1	1	1	1	1
13	1	1^x	1^x	1^x	2	2	2	2
14	2^x	2	2	2	2	2	2	2
15	1^x	1^x	1^x	1	1	1	1	1^x
16	1^x	2	2^x	2^x	2^x	2^x	2^x	2^x
17	2^x	2^x	2^x	2^x	2	2	2	1^x
18	1^x	1^x	1	1	1	1	1	1
19	1^x	1^x	1^x	2	2	2	2	2^x
20	2	2	2	2	2	2	2^x	2^x
21	2^x	2^x	2^x	2^x	2^x	2	2	2
22	2^x	2^x	2^x	2^x	2^x	3	3	2^x
23	2	2	2	2	2	1^x	1^x	1^x
24	1^x	2	1^x	1^x	1^x	1^x	1^x	1^x
25	1^x	1^x	1	0^x	0^x	0^x	0^x	0^x
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0^x	1
28	1	1^x	1^x	1^x	1^x	1^x	1	1
29	0^x	0^x	0^x	0^x	0^x	0^x	0^x	1
30	1	1	1	1	1	1^x	1^x	1
31	1	1^x	1^x	1^x	1	1^x	1^x	2^x

Day	February 1939							
1	2^x	3	3	3	3	3	3	3
2	3	2^x	2^x	2^x	2^x	2^x	2^x	2^x
3	2	2^x	2	2	2^x	2^x	2^x	2
4	2	2	1^x	1^x	1^x	1^x	1^x	2
5	2^x	2^x	3	3	3^x	4	4	4^x
6	4^x	4^x	4^x	4^x	4	3^x	3^x	3^x
7	3	2^x	2^x	2^x	2	1^x	1^x	1
8	1^x	1	1^x	1^x	1^x	2	2	2
9	2	2^x	2^x	2^x	2^x	2^x	2^x	2^x
10	2^x	3	3	3	3	3	3	3
11	2^x	2	1^x	1	0^x	0	0^x	0^x
12	0^x	0	0	0	0	0	0	0^x
13	1	1^x	1^x	2	2	2	2	2
14	2	2	2	2	2^x	2^x	2^x	2^x
15	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x
16	3	2^x	2^x	2^x	2^x	2^x	2^x	3
17	3	3	3	3	2^x	2^x	2^x	2^x
18	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x
19	2^x	2^x	2^x	2	2	1^x	1^x	1^x
20	1^x	1^x	1	1	1^x	1	0^x	0^x
21	0^x	0^x	0	0^x	0^x	0^x	0^x	1
22	1	1^x	1^x	1^x	1	1^x	1^x	1^x
23	1^x	1^x	2	2	2	2^x	3	4
24	4^x	5	5^x	5^x	6	6	6	5^x
25	5^x	4^x	4^x	3^x	3	2^x	2	1^x
26	1	1	1	1	1	1	1	1
27	0^x	1	1	1^x	1^x	1^x	2	2
28	2	2^x	2^x	2^x	2^x	3	3	3
29								
30								
31								

Day	March 1939							
1	3^x	3^x	4	4	4	4	3^x	3^x
2	3^x	3	2^x	2^x	2^x	3	3	3
3	3	3^x	3^x	3^x	3^x	3^x	3^x	3^x
4	3^x	3^x	3	3	3	2^x	2^x	2^x
5	2^x	2^x	2^x	2^x	2^x	3	3	3
6	3	3	3	2^x	2^x	2	2	2
7	1^x	1^x	2	2	2^x	2^x	2^x	2^x
8	2^x	2^x	2^x	2^x	2^x	3	3	3
9	3	3	3	2^x	2	2	2	2
10	2^x	2	2	2^x	2^x	2^x	2^x	2^x
11	2^x	2^x	3	2^x	2^x	2^x	2^x	2^x
12	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2
13	1^x	1^x	1^x	1^x	1^x	2	2	2
14	2	2	2	2^x	2^x	2^x	2^x	2^x
15	3	3	3	3	3^x	3^x	3^x	3^x
16	3^x	3^x	3	3^x	3	3	3	2^x
17	2^x	2^x	2	1^x	2	1^x	1^x	1
18	1	1	1	0^x	0^x	0^x	0^x	0^x
19	1	1^x	2	2	2	2	2^x	2
20	2	1^x	1^x	2	2^x	3	3	3^x
21	3^x	3^x	3^x	3^x	3^x	3^x	3^x	3^x
22	3^x	3^x	3^x	3^x	3^x	3	3	3
23	3	3	3	3	3	3	2^x	2^x
24	2^x	2^x	2	2	2	2	1^x	1^x
25	1^x	2	2	2	2	2	2	2^x
26	2^x	3	3	3	3	3	3	3^x
27	3^x	3^x	3^x	3^x	3^x	4	4	4
28	4^x	4^x	4^x	5	5	5	5	4^x
29	4^x	4^x	4^x	4	4	3^x	3^x	3^x
30	3^x	3^x	3^x	3^x	3^x	3^x	3^x	3
31	3	3	3	3	3	3	3	3

Day	April 1939							
1	3	3	3	3	3	3	3	3
2	3	3	2^x	3	3	3	3	3
3	2^x	3	3	2^x	2^x	2^x	2^x	2^x
4	3	3	3	3	3	3^x	3^x	3
5	3	2^x	2^x	2^x	2^x	2	2	2
6	1^x	1^x	1^x	1	1	1	1	1
7	1	1	1^x	1^x	1^x	1^x	1^x	2^x
8	2^x	2^x	2^x	2^x	2^x	2^x	3	2^x
9	2^x	3	3	3^x	3^x	3^x	3^x	3^x
10	4	4	3^x	3^x	4	3^x	4	3^x
11	3^x	3^x	3^x	3^x	3^x	3^x	3	3
12	3	2^x	2^x	2^x	2^x	2	2^x	2^x
13	2	2	2	2	2	2	2	2
14	2	2	2	2	2	2	1^x	1^x
15	1	1	1	1	1	0^x	0^x	0^x
16	1	2^x	3^x	5	5	5^x	6	6
17	6	6	5^x	5	5	4^x	4	4
18	4	4	4	4	4	4	4	4
19	4	4	4	4	4	3^x	3^x	3^x
20	3	3	3	3	3	3	3	3
21	3	3^x	3^x	3	3	3	3	3
22	3	2^x	3^x	4	4^x	5	5	5
23	5	5	5	4^x	4	3^x	3^x	5
24	5	5^x	5^x	5^x	6	6	5^x	5
25	4^x	4	3^x	3^x	3	3	2^x	2
26	1^x	1	0^x	0^x	1	0^x	0^x	0^x
27	2	2^x	2^x	2^x	3	3	3	3
28	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x
29	2^x	2^x	2^x	2	2	1^x	1^x	2
30	1^x	1^x	1^x	2	2^x	3^x	3^x	4
31								

Table 3--World-wide daily magnetic indices B, 1938-39--concluded

Day	May 1939								June 1939								July 1939								August 1939							
1	4	4x	4x	5	5	5	4x	4x	2x	3	3	3	3x	3x	3	3	2x	2x	2x	2x	2x	2x	2x	2x	1x	1	0x	0x	0x	0x	0x	0x
2	4x	4	4	3x	3x	3x	3	3	3	3	3	3	3	3	3	3	2x	2x	2x	3	3	3x	4	4x	0	0	0	0	0	0	0	0
3	3	3	3	2x	2x	2	2	2	3	3	3	3	3	3	3	3	4x	4x	4x	4	4	3x	3x	3x	0	0	0x	0x	0x	0x	0x	0x
4	1x	1x	2	2	2	2	2	3	3	3	2x	2x	2x	2x	2x	2x	4	4x	4x	5	5	5x	5x	5x	1	1	1	1	1	1	1	1
5	3x	3x	3x	3x	3x	4	4	4	2x	2x	2x	2	2	1x	1x	1x	5x	5x	5x	5	5	4x	3x	3	1	1	1	1	1	0x	0x	0x
6	4	4	4x	4x	4x	4x	4x	4x	1x	1x	1x	1x	1x	1x	1x	1x	2x	2	1x	1	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x
7	4	4	4	4	4	4	4	4	1	1	1x	1	1	1	1	1	0x	0x	0x	0x	0x	0x	0x	1	0x	0x	0x	0x	0x	0x	0x	1
8	4	3x	3x	3x	3x	3x	3x	3x	1	1	1	1	1	1	1	0x	1	1x	1x	1x	1x	1x	1	0x	1	1	1	1	1	1	1	0x
9	3	3	2x	2x	2	2	2	2	1	1	1x	1x	1x	2	2	2	0x	0x	0x	1	0x	0x	0x	1	0x	0x	0x	0x	2	2	2x	2x
10	2	2	2	1x	2	2	1x	1x	2	1x	1x	1x	1x	1x	1x	1x	1	0x	0x	0x	1	2	2	2x	2x	2x	2x	2x	2	2	2	2
11	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	2x	2x	2x	2x	2x	2x	3	2x	2x	3	4x	5	5	5	5x	5x
12	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	2	2	2x	2x	2x	2x	2x	2x	2x	1x	1x	5x	5x	5	4	4	4	4	4
13	1x	2	1x	1x	1x	1x	1x	1x	2x	3	3x	4	4x	4x	4x	4x	1x	1x	1x	2	3	3	3x	3x	3x	3	3	3	2x	2x	2x	2
14	1x	1x	1x	2	2	2	2x	2x	4x	4	4	3x	3	3	2x	2x	3x	3x	3x	3x	3	3	2x	2x	2	2	1x	1	1	0x	1	1
15	2x	2x	3	3	3	3	3	3	2x	2x	2x	3	3x	4	4	4	2x	2x	2x	2x	2x	2x	3	3	1	1	1x	1x	2	3	4	4
16	3	3	2x	2	2	2	2	2	3x	3x	3x	3	1x	1x	1	1	3x	3x	3x	3x	3x	3x	3x	3	4x	4x	4x	4x	4x	4x	3x	3
17	2x	2x	2x	2x	2x	2x	2x	2x	1	1x	2	2x	2x	3	3	3	3	3	3	2x	2x	2x	2x	2x	3	2x	2	2	1x	1x	1	1
18	2	2	2x	2x	2x	2x	2x	2x	3	3	3	3	3	3	3	3	2x	2x	2x	2x	2x	2x	2	2	1	1	1	1x	1x	2	2	2
19	2x	2x	2x	2x	3	3	3	3	3	3	3	3	3	3	3	3	2x	2x	3	3x	3x	4	4	4x	2	2	2	2	2	2	1x	1x
20	3	2x	2x	2	2	2	2x	3	3	2x	2x	3	3	3	3	3	4	4	4	3x	3x	4	4	4	1x	1x	1x	1x	1x	1x	1x	1x
21	3	3	3x	3x	3x	3x	3x	3x	3	3	3	3	3	3	3	2x	4	4	4	4	4	3x	3	3	2	3	4	4	4x	5	5x	5x
22	3x	3x	3x	3x	3x	3x	3x	3x	2x	2x	2x	2x	2x	2x	2x	2x	3	3	3	3	2x	2x	2x	2x	6	6	6	6	6	5x	5x	5x
23	3x	4	4	3x	3x	3x	3x	3x	2x	2x	2x	2x	2x	2x	2	2	2	2	2	2	1x	2	2	2	5	4x	4	4	3x	3	3	2x
24	3x	3	3	3	3x	3x	3x	3x	2	2	2	1x	1x	1x	1x	1x	2	2	2x	3	3	2x	2x	2x	2x	2x	2x	2x	2	2	2	2
25	3x	3x	3x	3x	3x	3x	3	3	1x	1x	1x	1x	2	2	2	2x	2x	2x	2x	3	3	3x	3x	3x	2	1x	1x	1x	1x	1x	1x	1x
26	3	2x	2x	2x	2x	2x	2	2	2x	2x	3	3	3	3x	3x	3	4	4	3x	3x	3	3	3	2x	1x	1x	1x	1x	1x	1x	1x	1x
27	2x	3	3	3	3	3	3	3	3	3	2x	2x	2	2	2x	2x	2x	2x	2x	2x	2x	2x	2	2	1x	1x	1x	1x	1x	1x	1x	1x
28	3	3	3	3x	3x	3x	4	4	3	3	3x	3x	3x	3x	3x	3x	2	2	2	1x	1x	1x	1x	1x	1	1x	1x	1x	1x	1	1	1
29	4	3x	3x	3	3	2x	2	1x	3x	3x	3	3	3	3	2x	2x	1x	1x	1x	1x	1x	1x	1x	1	1	0x	0x	0x	0x	0x	1	1x
30	1x	1x	1x	1x	1x	1x	1x	1x	2x	2x	2x	2x	2x	2x	2x	2x	1	1	1	1	1	1	1	1x	1x	1x	1x	1x	1x	1	1	1
31	1x	1x	1x	1x	1x	2	2x	2x									1x	1x	2	1x	1x	1x	1x	1x	1	1	1	1	1	1	1	0x

Day	September 1939								October 1939								November 1939								December 1939							
1	0x	0x	0x	1	1	1	1	1x	2	1x	1x	1x	1x	1x	1x	1x	2	1x	2	2	2	2	1x	1x	2	2	2	1x	1x	1x	1x	1x
2	2x	3x	4	4	4	4x	4x	4x	1x	2	2	2	2x	3	3x	4	1x	1x	1x	1	1	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x
3	4x	3x	3x	3	2x	2x	2x	2	4	4x	5	5	5	4x	4x	4	1x	1x	1x	1x	1x	1x	1x	1x	1x	2	1x	1x	1x	1x	1x	1x
4	1x	1	1	1	0x	0x	0x	0x	4	3x	2x	2x	3	2x	2x	2x	1	1	1	1	1	1x	1x	1x	1	0x	0x	0x	0x	1	1x	1x
5	0x	1	1	1	1x	1x	1x	2	2x	3	3x	3x	3x	3x	3x	3x	1x	1x	1x	1x	1	1	1	1	2	2	2	2x	2x	2x	2	2x
6	2	2	2	2	2	2	2	2	3x	3x	3	2x	2x	2x	2x	2	1x	1x	1x	1x	1x	1x	1x	1x	3	3x	4	4x	4x	4x	4x	4x
7	1x	1x	1x	1x	1x	1x	1x	1x	2	2x	2x	2x	2x	2x	2	2	1x	1x	1x	1	1	1x	1	1	4x	4	4	4	3x	3x	3x	3x
8	1x	2	2	2x	3	3	3	3x	2	2	2	3	3	3x	3x	3x	1	1	1	1x	1x	1	1	1	3x	3x	3x	3	3	3	3	3
9	3x	3x	3x	3x	3	3	3	3	3x	3x	3	2x	2x	1x	1x	1	1	1	1	0x	0x	0x	0x	0x	3	2x	2x	2x	2x	2	2	2
10	3	3	3	2x	2x	2x	2	2	1x	1x	2	2	2	2	2	2	0x	0x	0x	0x	0x	0x	0x	1	2	2	2	2	2	2	2	2
11	2	2	2	2	2x	2x	2x	2x	2x	2x	2	2	2	1x	1x	1x	1	1x	1x	1x	2	2	2x	2x	2	2	2	1x	1x	1x	1x	1x
12	2x	2x	2	2	2	2	1x	1x	0x	2	2x	3x	3x	4	4	5	2x	2x	2x	3	3x	4	4	4	2	2	2	2	2	2	1x	1x
13	1x	1x	2	2	2	2	2	2	5	5	5	5	5x	5x	5x	5	4	4x	4x	4	3x	3x	3x	3	1	1	1	1	1	0x	0x	0x
14	2	2	2	2	1x	1x	1x	1	5	5	5	5	5	4x	4x	4x	3	2x	2x	2x	2x	2	2	2	1	1	1x	1x	1x	1x	1x	2
15	1x	1x	1x	1x	1x	1x	1x	1x	4x	4	3x	3	3	3x	3x	3x	2	2	1x	1x	1x	1x	1	1	2	2	1x	1x	1x	1x	1x	1x
16	1x	1x	2x	2x	3	3	3x	4	3x	3x	4	4	4	4	3x	4	1	1	0x	0x	1	1	0x	1	2	2	2	2	2x	2x	2	2
17	4	4	4	4	4	3x	3	2x	3x	3x	3x	3x	3x	3x	3x	3x	1	1	1	1	1	1	1	1	1x	1	1	1	1	0x	0x	0x
18	2	1x	2	2	2x	3	3	3x	3x	3x	3x	3x	3x	3x	3	3	1	1	0x	0x	0x	1	1x	1x	0x	0	0x	0x	0	0	0	0
19	3x	4	4	4	4	4	4	4	3	3	2x	2x	2	1x	1x	1	2	2	2x	2x	2x	2	2	2	0	0	0	0	0	0	0x	0x
20	3x	3x	3	3	2x	2x	2x	2x	1	1	1	1x	1x	2	2	2x	1x	1x	1	1	1	1x	1x	1x	0x	1	1x	2	2x	3	3	3
21	2x	2x	2x	2	2x	2x	2x	2x	2x	2x	2x	2x	2x	2	2	2	1	1	1	0x	0x	0x	0	0	3x	3x	3x	3x	3	3x	3x	3x
22	2x	2x	2	2	1x	1x	1	1	1x	1x	1x	1x	2	2	2x	2x	0	0	0	0x	0x	0x	0x	1	3	3	3	3	3	2x	2x	2x
23	1	1	1x	1x	1x	1x	1x	1x	2x	2x	2x	2x	2x	2	1x	1x	1	1	1	1	1	1	1x	1x	2	2x	2	2	2	2	2	2
24	1x	1x	1	1x	1x	1x	2	2	1x	1	1	1	1	1x	1x	1x	2	2	2x	3	3	3	3	3	2x	2x	2	2	2	2	2	1x
25	2x	2x	3	3	3	3	3	3	1x	1x	1	1x	1x	1	1	1x	3	3	3	3	3	3	3	3	1x	1x	1x	1x	1x	1x	1x	1x
26	3	2x	2x	2	2	1x	1x	1x	1x	1x	1x	1	1	1	1x	1	2x	2x	2x	2	2	2	1x	1x	1x	1x	1x	2	2	2	2x	2x
27	1	1	1	1	1	1x	1x	1	1	1	1	1x	2	2	2	2	1x	1x	1x	1x	1x	1x	1x	1x	2x	2x	2x	2x	2x	2x	2	2
28	1	0x	0x	0x	1	0x	0x	0x	2	2	2x	2	2	2	2	2	1x	1x	1	1	1	1	1	1	2	2	2x	2	2	2	2x	2x
29	0x	0x	0x	0x	1	1	1	1x	1x	1x	1x	1x	1x	1x	1x	1x	1	1	1x	1x	1x	1x	1x	1x	2	2	2	2	2	2	1x	1x
30	2	2	2	2	2	2	2	2	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	2	2	2	2	2	1x	1x	1x	1x	1	1	1	0x
31									1x	1x	1x	1x	1x	1x	1x	2									0x	1	1	1	1x	1x	1x	2

Table 4--Monthly and annual frequencies of world-wide three-hour-range indices K_W, 1938-39, and average indices K_{Wm} and ranges A_K

Month	Frequencies of K_W =																			Total	Average	
	0	0ˣ	1	1ˣ	2	2ˣ	3	3ˣ	4	4ˣ	5	5ˣ	6	6ˣ	7	7ˣ	8	8ˣ	9		K_{Wm}	A_K
1938																						γ
Jan	5	22	21	25	33	35	32	20	16	11	8	5	3	6	1	1	2	1	1	248	2.72	44.7
Feb	20	14	28	26	37	31	26	18	6	10	4	3	1	.	.	.	.	.	.	224	2.14	23.2
Mar	40	42	41	28	22	16	25	10	10	8	4	2	.	.	.	.	.	.	.	248	1.63	17.9
Apr	19	18	27	33	41	35	27	15	9	6	3	2	2	1	.	1	.	.	1	240	2.14	27.8
May	8	31	42	39	29	35	29	9	10	6	3	2	1	2	1	1	.	.	.	248	2.04	23.8
Jun	23	38	56	39	24	20	19	8	8	4	1	.	.	.	.	.	.	.	.	240	1.55	14.7
Jul	26	31	38	47	29	23	18	12	10	7	3	3	1	.	.	.	.	.	.	248	1.79	19.1
Aug	36	49	31	21	27	31	25	10	7	4	4	1	1	1	.	.	.	.	.	248	1.66	18.1
Sep	16	21	30	48	48	24	14	11	7	8	6	3	3	1	.	.	.	.	.	240	2.02	22.8
Oct	29	28	19	26	37	35	28	17	12	10	2	3	2	.	.	.	.	.	.	248	2.05	22.6
Nov	15	36	36	49	24	33	19	15	10	1	2	.	.	.	.	.	.	.	.	240	1.76	16.6
Dec	31	33	29	38	35	26	21	13	10	9	3	..	.	.	.	.	.	.	.	248	1.78	18.1
Year	268	363	398	419	386	344	283	158	115	84	43	24	14	11	2	3	2	1	2	2920	1.94	22.5
1939																						
Jan	31	42	36	51	37	34	12	4	1	.	.	.	.	.	.	.	.	.	.	248	1.40	11.6
Feb	23	22	23	22	36	38	28	12	6	4	4	2	2	1	1	.	.	.	.	224	2.05	23.2
Mar	5	15	13	25	28	40	56	32	16	11	5	2	.	.	.	.	.	.	.	248	2.60	28.1
Apr	9	13	19	19	30	36	37	33	12	16	3	3	4	4	.	1	1	.	.	240	2.70	36.0
May	3	8	17	32	41	38	26	37	25	12	6	2	1	.	.	.	.	.	.	248	2.64	29.5
Jun	3	12	20	41	36	45	42	27	7	2	3	1	1	.	.	.	.	.	.	240	2.32	22.9
Jul	15	23	18	28	39	43	23	18	17	8	6	6	3	1	.	.	.	.	.	248	2.34	27.8
Aug	32	40	46	36	20	27	12	6	5	5	5	3	7	3	1	.	.	.	.	248	1.76	23.6
Sep	11	35	41	35	37	21	26	14	9	7	2	1	1	.	.	.	.	.	.	240	1.89	19.3
Oct	7	28	26	36	36	31	28	19	11	8	4	9	4	1	.	.	.	.	.	248	2.32	28.0
Nov	16	53	50	41	32	21	13	7	3	3	.	1	.	.	.	.	.	.	.	240	1.45	13.2
Dec	22	24	38	52	34	28	27	8	9	2	3	1	.	.	.	.	.	.	.	248	1.78	17.0
Year	177	315	347	418	406	402	330	217	121	78	41	31	23	10	2	1	1	.	.	2920	2.10	23.4

date, appear in the sixth column, but the B-index for the local date January 2 is entered as the sixth in the line marked January 1. Similarly, daily B-indices can be taken from Table 3 for intervals of the length of a day which begin less than 1.5 hours earlier or later than any local midnight.

Table 4—Monthly and annual frequencies are given in Table 4 for the world-wide indices K_w, and two kinds of monthly and annual averages, namely, the ordinary arithmetic average indices K_{wm}, and the world-wide equivalent three-hour ranges A_K expressed in γ, derived from the K_w by using Table 3 (p. 441) of our former paper.

Figure 3—Figure 3 is a graphical form of Table 4 giving the frequencies in per cent in the form of self-explanatory "trees" which permit recognition, at the same time, of the relative frequency of a particular index (for instance, $K_w=3$) and the relative frequency of any combination of indices (for instance, all indices from $K_w=0$ to $K_w=3$, inclusive). The trees give only one symbol for the combined frequencies of $K_w=$ 6 to 9; above the trees, each individual interval with $K_w=6$, 6^x, . . . , 9 is indicated by a Roman numeral.

§ 2. *Local features in the range-indices K*

It has been shown before[1]—and Table 1 provides more evidence—that the range-indices K determined at various observatories agree well, certainly better than any other proposed measure of magnetic activity for daily or shorter intervals. Certain local features, however, still remain in K beyond a scattering of a random nature, and, although

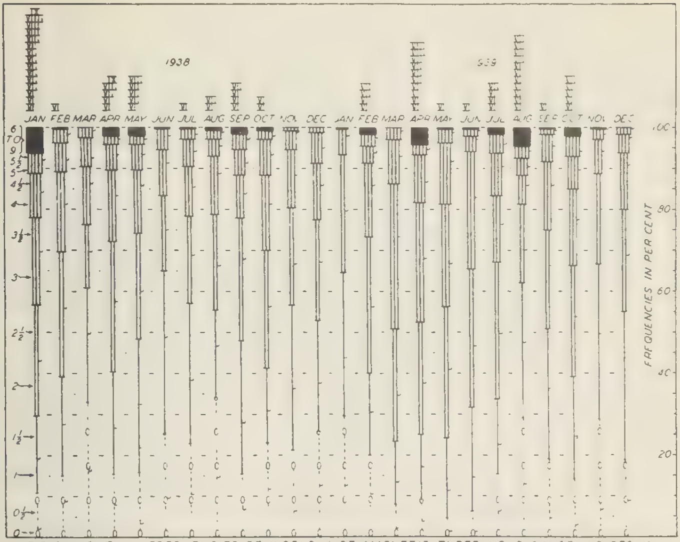


FIG 3—MONTHLY FREQUENCIES OF WORLD-WIDE MAGNETIC THREE-HOUR-RANGE INDICES K_W, 1938-39

these systematic individualities rarely exceed fractions of a unit in K, further improvement is desirable, especially in order to derive the best possible world-wide index of geomagnetic activity as a measure of solar corpuscular radiation P. These features are the following:

(*a*) *Differences in the general level of K*—Each of the scales proposed for K for the different observatories is defined by nine lower limits of ranges for the indices $K=1$ to 9; for instance, for Niemegk, the scale is 5, 10, 20, 40, 70, 120, 200, 330, and 500γ. All other K-scales are (approximately) multiples of the Niemegk scale, and can therefore be characterized by one parameter, for instance, the lower range-limit A_9 for $K=9$. The proposed scales give the choice between $A_9=300$, 350, 500, 600, 750, 1,000, and 1,500γ; the K-scale assigned to an observatory was selected so that, in a number of typical test-intervals, the number of K-indices of each kind was approximately the same at all observatories. This ideal could, of course, not be reached exactly; even systematic differences remained, since the low sensitivity of the magnetograms at some tropical observatories made it impractical to decrease the scale-limits sufficiently because it would have become too difficult to distinguish between $K=0$ and 1.

It is convenient, for the present, to conceive K as a *continuous* function of the range A; the lower range-limits for the integers correspond then to half-units (for Niemegk, for instance, $K=0.5$ to $A=5\gamma$, $K=1.5$ to $A=10\gamma$, etc.). Between $K=0.5$ and 3.5, the K-scale connects the range A and the index K with the parameter A_9 (the lower range-limit for $K=9$) by the equation

$$A=(A_9\ 100)\times 2^{(K-0.5)}$$

The same range A would, with another choice A'_9 for A_9, yield, instead of K, the value $K'=K+\log\ (A_9\ A'_9)\ \log\ 2$. Thus, with $A_9=300\gamma$ and $A'_9=350\gamma$, K becomes $K'=(K-0.22)$; or, with $A_9=350\gamma$ and

Table 5--Frequencies of three-hour-range indices K in the eight intervals of the Greenwich day, 1938-39

GMT	Season and number of intervals with values of K from 0 to 9																													
	Jan + Feb + Nov + Dec, 240 days										Mar + Apr + Sep + Oct, 244 days										May + Jun + Jul + Aug, 246 days									
h h	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	SITKA: 00^h GMT = 15^h standard 135° west meridian time																													
00-03	106	60	50	11	8	3	.	2	.	.	57	50	68	43	15	2	5	4	.	.	35	46	64	49	33	9	6	3	1	.
03-06	100	46	40	25	16	8	4	.	1	.	65	47	47	37	19	10	7	11	1	.	40	46	51	43	27	24	7	5	3	.
06-09	64	40	43	47	24	11	5	4	1	1	51	31	42	40	28	25	11	9	4	3	50	45	42	39	30	18	11	4	5	2
09-12	46	28	49	50	30	21	7	6	1	2	40	33	39	32	39	30	13	14	3	1	52	41	46	36	32	10	11	10	4	4
12-15	51	32	44	43	30	16	11	11	.	2	42	47	28	48	22	26	14	12	5	.	39	37	63	52	22	12	9	5	7	.
15-18	72	44	50	28	19	11	9	4	.	3	46	60	46	47	19	11	5	9	.	1	42	68	53	39	25	11	2	5	1	.
18-21	49	79	49	35	17	7	3	.	1	.	35	56	66	52	24	6	4	1	.	.	27	74	74	45	18	4	2	2	.	.
21-24	90	63	51	20	9	4	0	2	1	.	56	72	52	44	11	7	1	1	.	.	48	67	58	41	21	4	5	2	.	.
	NIEMEGK: 00^h GMT = 01^h standard 15° east meridian time																													
00-03	21	63	67	55	22	10	1	.	1	.	32	39	54	59	35	18	5	2	.	.	26	74	53	41	32	17	2	1	.	.
03-06	27	73	70	47	11	10	1	1	.	.	29	66	56	56	18	10	8	1	.	.	20	70	64	53	24	12	2	1	.	.
06-09	49	89	68	24	6	2	1	.	1	.	28	83	76	33	15	6	1	1	.	1	43	84	70	27	15	6	1	.	.	.
09-12	16	68	81	55	17	2	.	.	1	.	15	54	85	68	15	6	.	1	.	.	28	66	84	42	20	6	.	.	.	.
12-15	24	58	70	62	17	6	3	.	.	.	24	49	72	59	24	12	3	1	.	.	17	50	71	60	25	20	2	1	.	.
15-18	35	53	55	41	27	20	9	.	.	.	14	57	61	53	23	26	9	1	.	.	11	51	64	57	36	22	3	2	.	.
18-21	27	50	44	43	39	28	8	.	.	1	21	44	47	44	51	25	9	2	1	.	15	62	80	46	28	9	4	1	1	.
21-24	24	39	60	50	43	18	3	2	1	.	18	42	46	62	45	23	8	.	.	.	25	62	64	36	35	18	3	3	.	.
	CHELTENHAM: 00^h GMT = 19^h standard 75° west meridian time																													
00-03	42	70	49	47	17	10	3	.	2	.	38	37	44	54	38	20	10	3	.	.	34	40	60	48	34	21	6	2	1	.
03-06	44	58	55	45	26	7	4	1	.	.	36	44	48	56	34	10	11	5	.	.	31	47	48	52	37	21	9	.	1	.
06-09	53	51	54	51	16	11	3	1	.	.	43	51	47	49	29	16	5	2	.	2	34	56	53	54	22	17	8	2	.	.
09-12	58	55	46	48	24	7	1	.	.	1	51	48	51	55	23	11	4	.	1	.	47	59	53	42	27	13	4	1	.	.
12-15	53	66	44	54	14	6	.	2	.	1	45	55	72	37	19	13	2	1	.	.	52	53	70	41	14	11	5	.	.	.
15-18	68	61	54	29	19	4	2	2	1	.	42	65	58	50	21	4	3	1	.	.	37	42	79	53	27	3	3	2	.	.
18-21	42	65	65	41	20	5	1	.	.	1	21	45	54	79	29	12	3	.	.	1	14	44	74	59	39	9	6	.	1	.
21-24	46	58	66	40	19	7	1	1	1	1	22	43	60	61	37	12	7	2	.	.	16	36	61	60	44	16	7	5	.	1
	TUCSON: 00^h GMT = 17^h standard 105° west meridian time																													
00-03	33	81	64	37	12	8	4	1	.	.	33	42	55	62	31	13	6	2	.	.	32	52	64	46	32	15	3	2	.	.
03-06	37	59	70	41	20	9	4	.	.	.	33	45	57	54	27	13	11	4	.	.	33	45	44	57	44	16	6	1	.	.
06-09	44	56	60	54	12	10	3	1	.	.	29	57	51	52	33	14	4	3	.	1	33	46	51	56	39	13	8	.	.	.
09-12	39	67	64	44	18	6	1	.	.	1	42	54	49	57	32	6	3	1	.	.	45	56	59	54	18	10	4	.	.	.
12-15	51	69	55	37	20	4	3	1	.	.	46	60	62	43	20	11	1	1	.	.	51	58	71	35	20	8	3	.	.	.
15-18	57	60	54	30	19	15	3	2	.	.	31	69	66	43	20	12	3	.	.	.	29	66	72	44	22	9	3	1	.	.
18-21	39	57	66	52	13	8	4	1	1	.	24	61	61	58	25	13	1	.	1	.	17	67	70	60	19	10	2	1	.	.
21-24	38	59	68	39	27	4	4	1	.	.	26	45	56	71	31	11	4	.	.	.	23	55	65	44	35	18	4	2	.	.
	SAN JUAN: 00^h GMT = 20^h standard 60° west meridian time																													
00-03	33	87	64	38	10	5	2	1	.	.	35	42	63	60	25	13	4	2	.	.	36	66	57	49	28	6	4	.	.	.
03-06	41	72	70	42	8	6	1	.	.	.	27	56	73	54	19	10	4	1	.	.	38	45	57	63	38	3	1	1	.	.
06-09	51	81	63	34	6	4	1	.	.	.	46	61	69	44	14	7	1	1	.	1	42	64	70	43	17	10	.	.	.	.
09-12	42	80	74	34	8	1	.	.	.	1	49	56	65	49	18	5	2	.	.	.	42	62	73	50	11	6	2	.	.	.
12-15	44	69	64	47	10	3	2	1	.	.	56	54	62	42	25	1	4	.	.	.	44	69	68	44	15	5	1	.	.	.
15-18	32	64	81	33	19	8	1	2	.	.	36	61	74	46	16	8	3	.	.	.	21	73	78	54	15	4	1	.	.	.
18-21	37	61	78	40	12	6	3	2	1	.	36	44	59	69	22	9	3	1	1	.	21	70	75	46	22	10	1	1	.	.
21-24	38	77	57	39	19	6	2	1	1	.	34	53	61	58	25	11	2	.	.	.	32	65	68	42	29	6	2	2	.	.
	HUANCAYO: 00^h GMT = 19^h standard 75° west meridian time																													
00-03	46	86	61	36	8	2	1	.	.	.	31	63	67	59	16	5	3	.	.	.	52	77	48	43	19	4	3	.	.	.
03-06	59	87	61	24	6	2	1	.	.	.	37	69	74	43	9	8	4	.	.	.	53	58	48	58	24	4	1	.	.	.
06-09	67	96	60	11	5	.	1	.	.	.	47	84	63	38	5	5	1	.	.	1	69	55	72	33	14	3	.	.	.	.
09-12	35	80	85	28	11	.	.	.	1	.	38	73	71	44	16	2	.	.	.	.	55	84	66	28	12	1	.	.	.	.
12-15	7	24	59	74	50	21	1	4	.	.	12	29	62	75	38	22	5	1	.	.	13	44	64	69	33	13	8	2	.	.
15-18	2	12	42	78	49	38	12	6	1	.	2	10	34	83	63	35	13	4	.	.	4	23	61	68	51	26	10	1	2	.
18-21	7	28	50	89	36	18	10	1	.	1	4	22	60	79	45	23	9	1	.	1	14	47	77	55	32	16	3	.	2	.
21-24	39	52	84	44	15	3	2	1	.	.	28	74	73	46	16	4	3	.	.	.	75	66	48	31	20	5	1	.	.	.

Table 5--Frequencies of three-hour-range indices K in the eight intervals of the Greenwich day, 1938-39--concluded

GMT	Season and number of intervals with values of K from 0 to 9																													
	Jan + Feb + Nov + Dec, 240 days										Mar + Apr + Sep + Oct, 244 days										May + Jun + Jul + Aug, 246 days									
	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
h h	WATHEROO: 00^h GMT = 08^h standard 120° east meridian time																													
00-03	32	77	80	36	9	3	2	1	.	.	31	59	70	54	17	9	4	.	.	.	50	71	61	41	15	4	4	.	.	.
03-06	28	86	73	38	6	6	3	.	.	.	20	72	71	47	23	5	3	3	.	.	30	77	57	48	19	11	3	1	.	.
06-09	27	60	92	35	16	6	3	.	.	1	30	66	64	44	25	8	6	.	.	1	35	66	65	46	23	8	3	.	.	.
09-12	33	62	79	43	15	5	1	1	.	1	31	64	52	51	30	12	2	2	.	.	56	67	56	32	21	10	4	.	.	.
12-15	28	66	57	59	16	8	4	2	.	.	30	55	61	42	32	18	3	3	.	.	47	57	67	44	18	11	1	1	.	.
15-18	38	59	58	45	19	16	4	1	.	.	22	57	81	42	22	16	3	1	.	.	48	54	65	48	21	5	4	1	.	.
18-21	38	62	70	41	18	8	1	1	1	.	36	61	54	55	22	10	4	2	.	.	55	64	63	45	10	6	2	1	.	.
21-24	32	77	73	42	10	2	1	2	1	.	38	58	66	52	22	5	1	2	.	.	66	67	54	37	13	7	1	1	.	.
	HONOLULU: 00^h GMT = 13^h standard 165° west meridian time Six months only, January to June 1938, 181 days																													
00-03	41	57	37	23	11	11	1	.	.	.																				
03-06	50	44	40	27	9	8	3	.	.	.																				
06-09	40	40	41	34	13	9	2	1	.	1																				
09-12	35	36	48	41	10	8	1	1	1	.																				
12-15	49	32	44	34	16	4	1	1	.	.																				
15-18	65	44	39	21	8	3	1	.	.	.																				
18-21	34	61	47	23	9	5	.	2	.	.																				
21-24	24	52	53	29	13	5	4	1	.	.																				

$A'_9 = 500\gamma$, K becomes $K' = (K - 0.52)$. Since these examples consider the complete transition from one K-scale to the next higher scale, and since the majority of the K-indices is smaller than 4, it appears possible to select the K-scale so that the level of K is not more than 0.3 unit off the ideal scale. This is quite sufficient for K-indices for single intervals, since the natural individualities in activity make a sharper definition unnecessary.

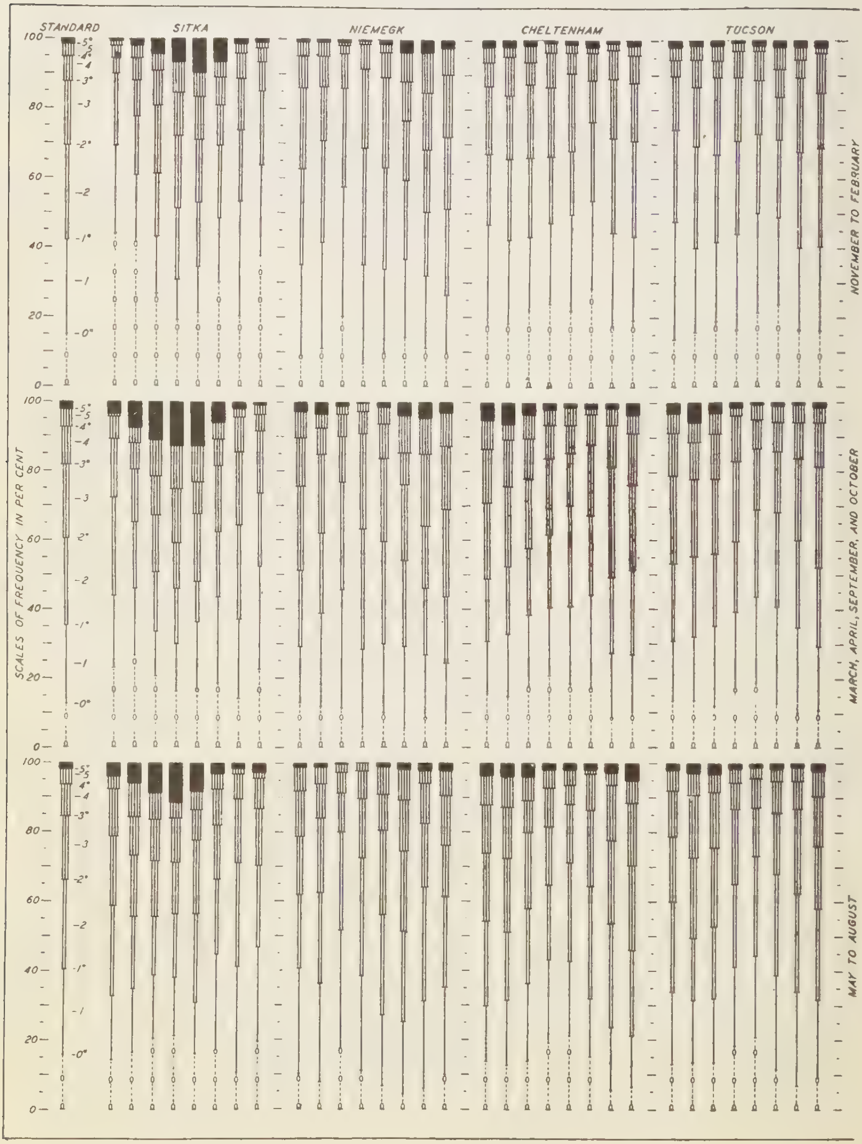
For establishing a standard for a world-wide index, however, it seems desirable to remove even these slight differences in the general level of the K-indices for the various observatories, together with the daily and seasonal effects to be considered next.

(*b*) *Daily variations of K*—At polar stations, geomagnetic activity is not evenly distributed over the day; at Sitka, the (local standard) hours 00^h to 09^h are, on the average, distinctly more disturbed than the hours 09^h to 21^h, while at Niemegk the (local standard) hours 16^h to 01^h are more disturbed than the hours 04^h to 10^h. This has been interpreted as indicating that the solar corpuscles are preferably guided into certain "target-sectors" in the two auroral zones, varying in the course of the day with the position of the Sun relative to the geomagnetic axis; in addition, the daylight ionization may influence the distribution and strength of the ionospheric currents started by corpuscles. K faithfully indicates the geomagnetic effects of such phenomena in a daily variation.

Huancayo, near the equator, gives an example of another type of daily variation in K; in the average for the eight equinoctial months, 1938-39, K is 3.5 for the (local standard) interval 10^h to 13^h, and only 1.6 for 01^h to 04^h. This expresses the fact that there are large irregular fluctuations in the horizontal intensity H at Huancayo around noon, but not in the night hours. These daytime fluctuations may be conceived as irregular changes in the ionospheric current-system which produces the regular daily variation S of H. A slight increase in the intensity P of solar corpuscular radiation seems to be associated with a noticeable

increase of these fluctuations, resulting in larger amplitudes and larger indices K; but some of these fluctuations may be actually "non-K-variations," for instance, solar-flare effects which are sometimes hard to diagnose.

Complete data on the daily variation of K in the years 1938 and 1939, as expressed in relative frequencies, and separate for the three usual seasons of four months each, are given in Table 5 and Figure 4; for



Honolulu, K-indices were available for the six months January to June, 1938, only. The first of the eight "trees" in each group in Figure 4 refers always to the interval 00^h to 03^h GMT, the second tree to 03^h to 06^h GMT, etc. Local standard midnight is at 09^h GMT at Sitka, 23^h GMT at Niemegk, 05^h GMT at Cheltenham, 07^h GMT at Tucson, 04^h GMT at San Juan, 11^h GMT at Honolulu, 05^h GMT at Huancayo, and 16^h GMT at Watheroo. The trees clearly express the features discussed

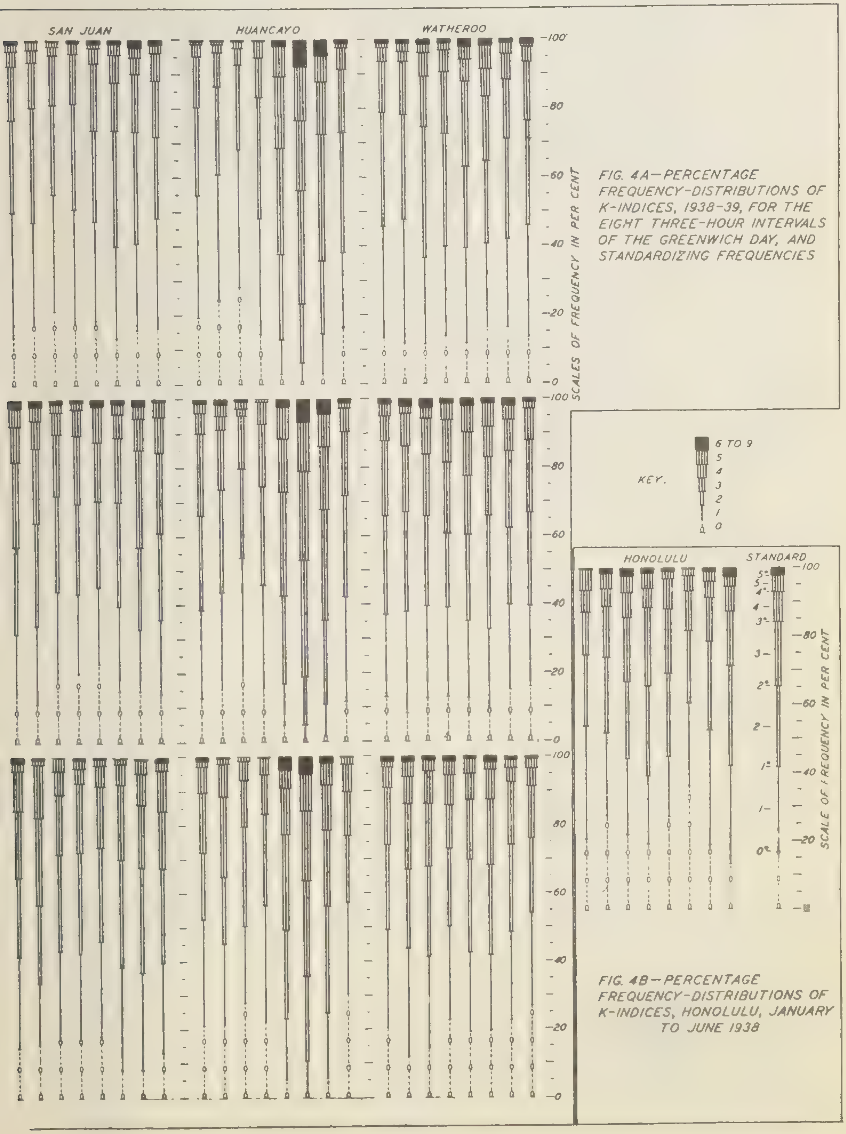


FIG. 4A—PERCENTAGE FREQUENCY-DISTRIBUTIONS OF K-INDICES, 1938-39, FOR THE EIGHT THREE-HOUR INTERVALS OF THE GREENWICH DAY, AND STANDARDIZING FREQUENCIES

FIG. 4B—PERCENTAGE FREQUENCY-DISTRIBUTIONS OF K-INDICES, HONOLULU, JANUARY TO JUNE 1938

above. Cheltenham and Watheroo stand out as having the smallest daily variations in K, while Huancayo has the largest variations.

(*c*) *Individual seasonal variations of K*—All good measures of magnetic activity show, in the average for several years, an annual variation with two maxima near the equinoxes. Even the two years 1938 and 1939 suffice to show this double wave, and the averages for K_w (arithmetic averages of the K_{wm} in Table 4) show a similar seasonal change as the average u_1-measure (based on day-to-day fluctuations of the ring-current) in the same years.

Averages for 1938-39	K_w	u_1
November to February	1.88	80
March, April, September, October	2.17	92
May to August	2.01	88

But the K-indices for certain observatories show, in addition, a slight tendency to higher averages for the summer months; this appears in Figure 4 and in Table 6, and in the following averages for the excess $(K-K_w)$, except for Niemegk:

Averages for 1938-39	$(K-K_w)$ for				
	Si	Ni	Ch	Hu	Wa
November to February	−0.06	+0.24	−0.04	+0.22	+0.01
May to August	+0.25	+0.17	+0.29	+0.01	−0.20
"Summer" minus "winter"	+0.31	−0.07	+0.33	+0.21	+0.21

Table 6--Total frequencies of three-hour-range indices K, 1938-39, and standardizing frequencies

Observatory	Frequency for K = 0	1	2	3	4	5	6	7	8	9	Observatory	Frequency for K = 0	1	2	3	4	5	6	7	8	9
Jan + Feb + Nov + Dec, 1938-39, 1920 intervals																					
Si	578	392	376	259	153	81	39	29	5	8	SJ	318	591	551	307	92	39	12	7	2	1
Ni	223	493	515	377	182	96	26	3	4	1	Hu	262	465	502	384	180	84	28	12	2	1
Ch	406	484	433	355	155	57	15	7	4	4	Wa	256	549	582	339	109	54	19	8	2	2
Tu	338	508	501	334	141	64	26	6	1	1	Stand	285	519	528	352	139.	65	20	7	3	2
Mar + Apr + Sep + Oct, 1938-39, 1952 intervals																					
Si	392	396	388	343	177	117	60	61	13	5	SJ	319	427	526	422	164	64	23	5	1	1
Ni	181	434	497	434	226	126	43	9	1	1	Hu	199	424	504	467	208	104	38	6	.	2
Ch	298	388	434	441	230	98	45	14	1	3.	Wa	238	492	519	387	193	83	26	13	.	1
Tu	264	433	457	440	219	93	33	11	1	1	Stand	239	452	492	412	210	98	35	12	1	1
May + Jun + Jul + Aug, 1938-39, 1968 intervals																					
Si	333	424	451	344	208	92	53	36	21	6	SJ	276	514	546	391	175	50	12	4	.	.
Ni	185	519	550	362	215	110	17	9	1	.	Hu	335	454	484	385	205	72	26	3	4	.
Ch	265	377	498	409	244	111	48	12	3	1	Wa	387	523	488	341	140	62	22	5	.	.
Tu	263	445	496	396	229	99	33	7	.	.	Stand	306	486	506	363	185	86	27	8	1	0
January to June 1938, 1448 intervals																					
Ho	338	365	350	232	89	53	13	6	1	1											
Stand	244	359	340	273	130	66	21	8	4	3											

§ 3. *An ideal scheme of measuring magnetic activity*

A complete and homogeneous description of the magnetic activity by three-hour-range indices would be possible in a sufficiently dense net of observatories, say, O_1, O_2, O_3, . . . , evenly spaced all over the Earth operating simultaneously for a number of sunspot-cycles. The ideal scheme would begin:

(*a*) By determining, from records of three rectangular force components, for each observatory separately, the three-hour-ranges for the most disturbed force component in each interval.

(*b*) The relative frequencies of these ranges for each observatory, for the whole series of observations, are then given by a frequency-

range scale (say, $F(O_1)$, $F(O_2)$, . . .) from 0 to 100 per cent, similar to the "trees" in Figure 4.

(*c*) A standard scale of the same length, showing the dividing marks for the lower range-limits for $K=1, 2, \ldots, 9$, is then adopted by an independent choice, based on experience on the magnitude of magnetic disturbance, so that the standard scale is suitable for describing activity.

(*d*) This standard scale is then fitted to each of the range-frequency-scales $F(O_1)$, $F(O_2)$, . . . , and opposite the marks on the standard scale, a set of nine lower range-limits is read from $F(O_1)$ to give, once for all, the K-scale for the observatory O_1, from $F(O_2)$ to give the K-scale for the observatory O_2, etc. (principle of the *assimilation of frequency-distributions*).

(*e*) With these K-scales the ranges are converted into K-indices for each observatory. The process (*d*) guarantees that each observatory assigns the same aggregate number of indices $K=0$, $K=1$, etc.

(*f*) The average of the K-indices for all observatories gives the world-wide index for each three-hour interval.

§ 4. *The reduced indices K_r*

In practice this ideal scheme can only be approximated. But there is only one fundamental point in which the limited number of observatories, and their haphazard distribution over the Globe, force a major deviation: In the ideal scheme, namely, small systematic differences in the average world-wide indices for the eight intervals of the Greenwich day might be found, indicating a *universal* daily variation of magnetic activity which has often been sought. Now the daily variations of K at each observatory must contain two parts, this universal part superposed by a truly local variation. In the average of the K-indices from well-distributed observatories, the average local variations are suppressed; but it is clear from the data discussed in § 2 (*b*) that, in the average for our eight observatories, this process of elimination of local features is by far not completed, and the average daily variation of K would, at best, be a very biased image of a possible universal daily variation. Therefore, it was decided to apply the standardizing process [§ 3 (*d*)] to each of the eight intervals of the Greenwich day separately. This eliminates the local daily variation of K, but obliterates also the possible universal daily variation in the world-wide index. This sacrifice is necessary to insure sufficient homogeneity of the world-wide index, and is no irretrievable loss since the original K-indices remain available as material for an independent search after the universal variation.

Our standardization uses the K-indices for seven observatories for the two years 1938-39, and is made separately for each of the usual seasons (November to February; equinoxes = March, April, September, October; May to August), As standard (K_r) the total frequencies for Niemegk, Cheltenham, and Watheroo were used in the combination [(Niemegk + Cheltenham + 2 × Watheroo) 4], which gives equal weight to the two hemispheres in order to balance the (small) individual seasonal variations in K discussed in § 2 (*c*).

The frequency-scales $F(O_1)$, etc., are given in Figure 4 in the form of the K-trees, and the standardization consists in coordinating a "***reduced range-index***" K_r, to half units, to each K. The trees for K_r are shown at the left in Figure 4 as "standard." The assimilation of the frequencies of K and K_r means: If the percentages of total frequencies $K=0$ to K are $N(K)$, and $K_r=0$ to K_r are $N_r(K_r)$, the coordination K_r to K is defined by $N(K)=N_r(K_r)$. In practice, as already mentioned in § 2 (*a*), a dividing mark on the K-tree, for instance, between $K=2$

Table 7--Conversion of original three-hour-range indices K to reduced indices K_r

Season	K	Sitka								Potsdam-Niemegk								Cheltenham								Tucson						
January, February November, December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	2	2	1	1	1	1x	1x	2	0x	1	1x	0x	0x	1	0x	0x	1	1	1	1	1x	1x	1	1	1	1	1	1	1	1x	1
	2	3	2x	2	1x	1x	2	2x	2x	2	2	2x	2	2	1x	1x	1x	2	2	2	2	2	2x	2	2	2	2	2	2	2	2	2
	3	4	3	2x	2	2	2x	3	3x	2x	3	4	3	3	2x	2	2	3	2x	3	3	3	3	3	3	3	3	3	3	3	3	3
	4	5	4	3x	3	3	3x	4	4x	4	4	5	4x	4	3	3	3	4	3x	4	4	4	4	4	4	4	4	4	4	4	3x	4
	5	5x	5	4	3x	3x	4	5	5x	5	5	6	6	5	4	4	4x	5	5	5	5x	5	5	5x	5	5	5	5	5x	5	4x	5
	6	6	6	5	4x	4x	5	6	6x	6	6	7	7	6	5	5	5x	6	6	6	6x	6	6	6x	6	6	6	6	6x	6	5x	6
	7	7	7	6x	5x	5x	6	7	7	7	7	8	8	7	6x	6x	6x	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	8	8	8	7x	7	6x	7	8	8	8	8	8x	8x	7	7x	7x	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
March, April, September, October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1x	1x	1	1	1	1x	1	1x	1	1	1	0x	1	0x	0x	0x	1	1	1	1x	1	1x	0x	0x	1	1	1	1	1x	1	1
	2	2x	2x	2	1x	2	2	2	2x	1x	2	2x	2	2	2	1x	1x	1x	2	2	2	2x	2x	1x	1x	2	2	2	2	2x	2x	2
	3	3x	3	2x	2	2x	3	3	3x	2x	3	3x	3x	3	2x	2x	2x	2x	2x	3	3	3x	3x	2x	2x	3	3	3	3	3x	3x	3
	4	4x	3x	3	3	3	4	4x	4x	3x	4	4x	5	4	3x	3	3x	3x	3x	3x	4	4	4x	4	3x	4	3x	3x	4	4x	4	4
	5	5	4x	3x	3x	3x	4x	5x	5x	4x	5	5x	6	5	4x	4	4	4x	4x	4x	5	5	5x	5	4x	4x	4x	4x	5x	5x	5	5x
	6	6	5	4x	4	4	5	6	6x	5x	6	6x	7	6	5x	5	5x	5x	5	5x	6	6	6x	6	5x	5x	5	5x	6x	6x	6	6x
	7	7	6	5x	5	5	6	7	7	7	7	7x	8	7	6x	6	6x	6x	6	6x	7	7	7x	7	6x	7	6	7	7x	7	7	7x
	8	8	7x	7x	7	6x	7x	8	8	8	8	8	8x	8	7x	7x	7x	7x	7x	7x	8	8	8	8	7x	8	7x	8	8x	8	8	8x
	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
May, June, July, August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	1	1	1x	1	0x	0x	0x	1	1	1	1	1	1	1	0x	0x	1	1	1	1	1	1	0x
	2	1x	1x	2	2	1x	2	2	2	2	2	2x	2	1x	1x	2	2	1x	1x	2	2	2	2	1x	1	2	1x	1x	2	2	2	2
	3	2x	2x	2x	2x	2x	3	3x	3	2x	3	3x	3x	2x	2x	3	2x	2x	2x	2x	3	3	3	2x	2	2x	2x	2x	3	3	3	3
	4	3x	3	3	3	3x	3x	4x	4	3x	4	4x	4x	3x	3x	4	3x	3x	3	3x	4	4	4	3x	3	3x	3x	3x	4	4	4	4
	5	4x	4	4	3x	4	4x	5x	5	5	5	5x	5x	4x	4x	5	4x	4x	4	4x	5	5	5x	5	4	5	4x	4x	5	5	5	5
	6	5x	5	4x	4	4x	5x	6x	6	6	6	6x	6x	6	6	6	6	5x	5	5x	6	6	6	6	5	6	5x	5x	6	6	6	6
	7	6x	6	5x	5	5x	6x	7x	7	7	7	7x	7x	7	7	7	7	6x	6	6x	7	7	7	7	6	7	6x	6x	7	7	7	7
	8	7x	7x	7	6x	7	7x	8	8	8	8	8x	8x	8	8	8	8	7x	7x	7x	8	8	8	8	7x	8	8	7x	8	8	8	8
	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9

Season	K	San Juan								Honolulu								Huancayo								Watheroo						
January, February November, December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1x	1	1	1	1	1	1x	1x	1	1	1x	2	1	1	1x	1x	1x	1	0	0	0	1	1	1	1	1	1	1	1
	2	2x	2x	2x	2x	2	2	2	2	2x	2x	2	2	2	3	2x	2	2x	2x	3	2x	1	0x	1	2	2x	2x	2	2	2	2	2
	3	3x	3x	3x	3x	3	3	3	3	3x	3x	3	3	3	4	3x	3	3x	4	4x	3x	2	1x	2	3	3x	3x	3	3	2x	2x	3
	4	4x	4x	5	5	4x	4	4	4	4	4x	4	4x	4x	5	4x	4	5	5	5x	5	3	2x	3	4x	4x	4x	4	4x	4	3x	4
	5	5x	5x	6	6x	5x	5	5	5	5x	5	5	5	5x	6	5x	5	6	6	6x	6	4x	3x	4	5x	5x	5x	5	5x	5	4x	5
	6	6x	6x	7	7x	6x	6	6	6	6x	6	6	6	6x	7	6x	6	7	7	7x	7	5x	4x	5	6x	6x	6	6	6	6	5x	6
	7	7	7x	7x	8	7x	7	7	7	7x	7	7	7	7	8	7	7	7x	7x	8	8	6x	5x	6	7	7	7	7	7	7	7	7
	8	8	8	8	8x	8	8	8	8	8x	8	8	8	8	8x	8	8	8	8	8x	8x	7x	7	7	8	8	8	8	8	8	8	8
	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
March, April, September, October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1x	1x	1x	1	1	1	1x	1x	1	1	1x	2	1	1	1	1	1x	1x	0x	0	0	1	1	1	1	1	1	1	1
	2	2	2	2x	2x	2x	2x	2	2	2x	2x	2	2	2	3	2x	2	2	2x	3	2x	1x	0x	1	2x	2	2	2	2	2	2	2
	3	3	3	3x	3x	3x	3x	3	3	3x	3x	3	3	3	4	3x	3	3x	3x	4	3x	2x	1x	2	3x	3	3	3	3	3	3	3
	4	4	4	4x	4x	4x	4x	4	4	4	4x	4	4x	4x	5	4x	4	4x	4x	5	5	3x	3	3x	4x	4x	4x	4	4	3x	4	4
	5	5	5	5x	5x	5x	5x	5	5x	5x	5	5	5	5x	6	5x	5	5x	5x	5x	6	4x	4	4x	5x	5x	5x	5	5	4x	5	5
	6	6	6	6x	6x	6	6	6	6x	6x	6	6	6	6x	7	6x	6	6x	6x	6x	7	6	5	5x	6x	6	6	6	6	6	6	6
	7	7	7	7	7x	7	7	7	7	7x	7	7	7	7	8	7	7	7x	7	7x	8	7	6	6x	7x	7	7	7	7	7	7	7
	8	8	8	8	8x	8	8	8	8	8x	8	8	8	8	8x	8	8	8	8	8x	8x	8	7	7x	8	8	8	8	8	8	8	8
	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
May, June, July, August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	1x	1x	1	1	1x	2	1	1	1x	1	1x	1x	0x	0	0x	1x	1x	1	1	1x	1	1	1x
	2	2	1x	2	2	2x	2	2	2	2x	2x	2	2	2	3	2x	2	2x	2	2x	2x	1x	1	1x	2x	2x	2	2	2x	2	2	2x
	3	3	2x	3x	3x	3x	3x	3	3	3x	3x	3	3	3	4	3x	3	3x	3	3x	4	2x	2	2x	3x	3x	3	3	3	3	3	3x
	4	4	4	4x	4x	4x	5	4	4	4	4x	4	4x	4x	5	4x	4	4x	4x	5	5x	3x	3	3x	4x	4x	4	4	4	4	4	4x
	5	5	5x	5x	5x	5x	6	5x	5	5x	5	5	5	5x	6	5x	5	5x	6	6x	6x	4x	4	4x	5x	5x	5	5	5	5	5	5x
	6	6	6x	7	6x	6x	7	6x	6	6x	6	6	6	6x	7	6x	6	6	7	7x	7x	5x	5	6	6x	6	6	6	6	6	6	6x
	7	7	7x	8	7x	7x	8	7x	7	7x	7	7	7	7	8	7	7	7	7x	8	8	6x	6	7	7x	7	7	7	7	7	7	7x
	8	8	8	8x	8	8x	8x	8	8	8x	8	8	8	8	8x	8	8	8	8	8x	8x	7x	7	8	8x	8	8	8	8	8	8	8
	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9

Note: Sign x following entry indicates value is to be increased by 1/2; thus, 0x = 0.5, 1x = 1.5, etc.

and $K=3$, should, on a *continuous* frequency-scale, be ciphered $K=2.5$ (written $2^{\times}$) while the mark for $K=2.0$ should lie near the middle of the stretch expressing the frequency of $K=2$, and is best determined by a graph with K as abscissa, $N(K)$ as ordinate. The standard scales at the left have been marked accordingly. The standardizing process § 3 (c) has been then realized by drawing, through the marks on the K-trees, horizontal lines across to the standard K_r-trees. $K=0$ and $K=9$ were always retained as $K_r=0$ and $K_r=9$; the horizontal lines cut across the standard trees at values giving K_r, to the nearest half unit, for $K=0$ to 5. The values K_r for $K=6$ to 9 are then interpolated, because the scarcity of these indices in each sub-group makes it impractical to use the actual observations for standardizing. The result is expressed in the conversion-keys, Table 7, which are applicable, of course, not only for 1938 and 1939, but also for other years, until much more material has accrued to warrant a revision of these keys.

The keys show, by the way, that a simple "reduction-factor" would not work; for instance, for Sitka, K_r for $K=1$ is mostly greater than 1, but K_r for $K=7$ is smaller than 7. On the other hand, the keys for the three seasons differ so little that not much could have been gained by making keys for individual months; for the same reason, the uniform key for Honolulu may be safely applied for all seasons alike.

The following averages for the equinoxes 1938 to 1939 demonstrate the success of the standardization in eliminating rather pronounced local features.

Three-hour interval GMT	Original K-indices				Reduced K_r-indices			
	Si	Ni	SJ	Hu	Si	Ni	SJ	Hu
h h								
00–03	1.82	2.49	2.26	1.98	2.18	2.15	2.26	2.15
03–06	2.07	2.15	2.14	1.83	2.12	2.15	2.14	2.11
06–09	2.70	1.83	1.82	1.57	2.23	2.10	2.22	2.15
09–12	2.96	2.15	1.81	1.73	2.17	2.27	2.21	2.19
12–15	2.80	2.26	1.77	2.78	2.23	2.26	2.15	2.31
15–18	2.15	2.55	1.92	3.53	2.20	2.20	2.22	2.30
18–21	2.05	2.76	2.20	3.05	2.11	2.25	2.19	2.23
21–24	1.64	2.72	2.12	1.89	2.02	2.25	2.14	2.18
Total average	2.27	2.36	2.00	2.30	2.16	2.20	2.19	2.20

§ 5. *The world-wide index*, K_w

In combining the reduced indices K_r, only half weight was given to the results for Tucson, San Juan, Honolulu, and Huancayo, because the magnetic effects of solar corpuscular radiation, especially the lower degrees $K=0$ to 3, are naturally more easily distinguished in the magnetograms of polar stations. The weighted averages, carried to half units, are the world-wide indices K_w given in Table 2; these are further converted into daily indices B and monthly averages K_{wm} and ranges A_K in Tables 3 and 4.

Acknowledgments—More than 40,000 original K-indices have been communicated in this and the preceding paper, together with 5840 world-wide indices K_w and the same number of daily indices B. We acknowledge with thanks valuable assistance given by Dr. G. Fanselau and Dr. A. Burger of the Geophysikalisches Institut Potsdam; L. Hurwitz of the United States Coast and Geodetic Survey; W. E. Scott, W. C. Hendrix, and Miss E. Balsam of the Department of Terrestrial Magnetism, Carnegie Institution of Washington.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington (J. B. and H. F. J.),
Washington, D. C.
United States Coast and Geodetic Survey (N. H. H.),
Washington, D. C.

LETTERS TO EDITOR

(See also pages 344 and 371)

PROVISIONAL SUNSPOT-NUMBERS FOR MAY AND JUNE, 1940

(Dependent alone on observations at Zürich)

Day	May	June
1	*E*26[ac]	*M*38[c]
2	28	41
3	23	*E*77[cd]
4	25	80
5	. .[a]	58[a]
6	21	95[dd]
7	22	94
8	*E*32[c]	106
9	*E*31[c]	102
10	34	107
11	36	109
12	*M*53[acd]	*M*94[aac]
13	62[a]	104
14	93[a]	*M*76[c]
15	91	82
16	85	59[d]
17	. .	. .
18	63[a]	51
19	69[a]	46[d]
20	*M*61[c]	38
21	*E*71[ac]	*E*58[c]
22	86	61[b]
23	85[d]	83
24	67	*E*113[c]
25	*E*76[ac]	108[b]
26	57	*E*136[c]
27	61[a]	117
28	62	120[a]
29	. .[a]	104[a]
30	. .	103
31	54	
Means......	54.6	84.8
No. days....	27	29

Mean for quarter, April to June, 1940: 67.0 (85 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disk; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

SOLAR RADIATION AND GEOMAGNETISM

By J. Bartels

Summary—Solar wave-radiation, W, and corpuscular radiation, P, may be estimated in their variations of intensity by their geomagnetic effects. A classification of magnetic storms is proposed, and geomagnetic evidence for the travel-times of solar corpuscles is discussed.

(1) The theory of geomagnetic time-variations leads to the working hypothesis that the Sun, in addition to rays penetrating to the ground, sends us ionizing radiation to be classified as wave-radiation, W, and particles, P. Studies of the ionosphere by means of wireless waves support this idea. W ionizes the dayside of the ionosphere and is geomagnetically effective in the solar and lunar daily variations, S and L; P also reaches the Earth's nightside, mainly in polar regions, and produces auroral and magnetic disturbances with their associated effects. The intensities of both W and P vary in parallel with the 11-year sunspot-cycle (expressed in the relative sunspot-numbers R), but with the difference that P lags behind R, while W shows no lag.

(2) Adolf Schmidt, in his well-planned "Archiv des Erdmagnetismus," collected data for S, in monthly means, for many observatories, and represented S as a linear function of R. This work has been the model for the plan to ascertain, day by day, by means of S, the fluctuations $\triangle W$ of W. For this purpose, S must be freed from secondary influences, namely, L, the non-cyclic change, and the disturbance daily variation, S_D. S_D, an effect of P, can be neglected in non-polar regions when the international magnetic character-figure is less than 1.2. The non-cyclic change (the decay of the ring-current effect after disturbances) can be easily eliminated, and is small in comparison with S. But L is sometimes surprisingly strong (see section 3), and the change of L with the Moon's phases must not be misinterpreted as variability of S.

S may be schematically described as the effect of two ionospheric current vortices, with centers on the 11 o'clock meridian, progressing along about 35° latitudes. A still simpler picture is that of a gigantic vertical horseshoe-magnet rotating around the Earth in the 11 o'clock meridian, with the south pole over 35° north latitude, and the north pole over 35° south latitude. These equivalent pictures illustrate those features in the daily variations of the north-, east-, and vertical-force components X, Y, and Z, which express most clearly the intensity of S and, thereby, $\triangle W$, namely: Near the equator the daytime rise of X over the night-level; in northern middle latitudes, the daily wave in Y, with the morning maximum and the afternoon minimum, and the daytime decrease in Z; in southern middle latitudes, the daily variations in Y and Z as in the north, but with reversed signs.

By induced currents in the Earth's interior, S is magnified in X and Y, and weakened in Z; the effect of these currents exceeds by far any (opposed) effect of magnetic polarization in the Earth's body. This leaves, as most suitable for measuring $\triangle W$, the daily ranges, A (amplitudes, to be defined later) of X (or of the horizontal force H) near the

equator, and of Y (or of the declination D) in middle latitudes. The annual variation of A is eliminated by computing for each calendar day a value of A corresponding to $R=50$; the normalized deviations $\triangle A$ from this value, expressed as multiples of their standard deviations, measure $\triangle W$.

(3) For Huancayo (Peru), near the magnetic equator, A for H was defined as the excess of the five-hour average 9^h to 14^h (standard time) over the night-level, given by a straight line connecting the five-hour averages 0^h to 5^h. L appears in A as a wave with the period of half a month: In the average for the months November to February, near sunspot-maximum ($R=93$), this lunar semimonthly wave has its maximum, $A=149\gamma$, four days after new and full Moon, and its minimum, $A=99\gamma$, a quarter month later. Elimination of L is therefore necessary so that $\triangle W$ may be inferred from corrected ranges A_S, or their deviations $\triangle A_S$ as described above. The correlation-coefficients, r, between the monthly means 1922-39 for $\triangle A_S$ and R are very high: For the 18 months of September $r=+0.966$, and r for no calendar month is smaller than $+0.89$; each of the usual four-month groups (November to February, May to August, and equinoxes) yields $r=+0.97$, and averages for whole years yield $r=+0.984$. These are the closest statistical correlations so far found between phenomena on the Sun and on the Earth. In addition they show that the sunspot-numbers R are quite a good measure for the wave-radiation W.

For Potsdam, A has been computed so far for the months April to September only, as difference of the four-hour averages of Y, 5^h to 9^h minus 11^h to 15^h, universal time. For Watheroo (Western Australia), preliminary calculations for A (D) show similarly large lunar effects as in A (H) for Huancayo. It is planned to compute daily ranges of A on days not too strongly disturbed for more observatories to utilize the geomagnetic records more fully for measuring W.

(4) The intensity of the solar corpuscular radiation P is recognized in its effect on geomagnetic disturbance, the intensity of which may be expressed by various measures of activity.

In Figure 1, a measure for P is shown which is derived from the u_1-measure of magnetic activity by eliminating the systematic annual variation of u_1; it is compared with the sunspot-number R and with a geomagnetic measure for W derived from $A(H)$ for Huancayo. The three measures are normalized in the sense that the standard deviations for the 70 quarterly means are the same; one scale-division equals 0.4 of the standard deviation. The greater similarity between W and R than between P and R is expressed in the correlation-coefficients for the quarterly means shown, namely: $r(W, R)=0.968$; $r(P, R)=0.860$; $r(P, W)=0.843$. The curve for P lags behind R. The curves for R and W agree better, not only in the general trend of the 11-year cycle, but also in many details, for instance, in the apparent subcycle of about 15 months in the years 1924-30, or in the steep increase in the last quarter of 1936, or in the first quarter of 1939. But there are also significant discrepancies, for instance, the comparatively larger fluctuations of W in the sunspot-minimum; the epochs of the sunspot-maxima in 1928 and 1937 are more marked in W than in R.

For a new measure of P, the measuring principle of the "Potsdamer Erdmagnetische Kennziffer" $K=0$ to 9, introduced in 1938, has been

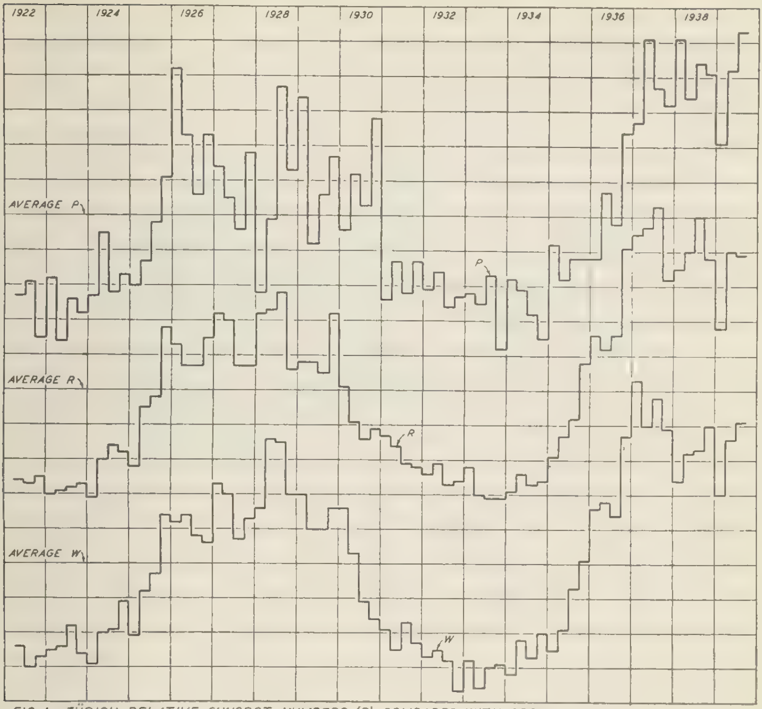


FIG. 1—ZÜRICH RELATIVE SUNSPOT-NUMBERS (R) COMPARED WITH GEOMAGNETIC MEASURES OF SOLAR CORPUSCULAR RADIATION (P) AND SOLAR WAVE-RADIATION (W); QUARTERLY MEANS, 1922-39 [UNITS CHOSEN SO THAT THE STANDARD DEVIATION FOR EACH CURVE EQUALS 2.5 SCALE-DIVISIONS]

adopted for a three-hour-range index by several American observatories. Residual local influences on K will be eliminated by "assimilation of frequency-distributions." This normalization of scales for K may be described in the following example: For each three-hour interval, two range-indices K_1 and K_2 may be given. For a great number of intervals the relative frequencies are counted and the summed frequencies $N_1(K_1)$ = total number of all indices under K_1, and $N_2(K_2)$, are formed. The key for the coordination of the scales for K_1 and K_2 is then given by $N_1(K_1) = N_1(K_2)$. Such keys for the transition from K to a "reduced index" K_r are already available, and these K_r will be combined to yield world-wide indices in which K-indices from observatories in the tropics, where the influence of P is less distinct, will enter with less weight than those from stations near the auroral zones.

The agreement between simultaneous range-indices all over the Globe expresses the fact that clouds of solar particles are much more extended than the Earth. Range-indices $K = 0$ for the whole Earth are rather rare, certainly less than ten per cent. But even $K = 0$ means only that the intensity of disturbance does not exceed a certain threshold; in fact, a complete absence of the slightest disturbance for a full three-hour

interval is very rare. This means that the Earth is almost constantly, even near sunspot-minimum, under the influence of (presumably solar) particles, weak as this influence may be at times; a wide scale of increasing activity also includes the strongest magnetic storms ($K=9$), in which the ionospheric currents reach millions of amperes.

(5) The solar corpuscular radiation P can so far be recognized only when it reaches the Earth. The 27-day recurrence tendency of the weaker degrees of magnetic activity ($K=2$ to 5) has been interpreted as indicating hypothetical "M-regions" on the Sun's surface which, through several solar rotations, emit clouds of particles; these clouds of various sizes, from mere "wisps" to diameters many times the Earth's radius, taken together form a more or less continuous stream perhaps of the structure of a string of pearls and in shape like the arm of a spiral nebula.

In single cases of especially strong storms it has been suggested that, in addition to the "impact" on the Earth, the time and location of the "firing" of this cloud has been observed in the spectrohelioscope as an intense eruption. The wave-radiation of these solar "flares" increases W temporarily in quantity and changes perhaps also the quality. Thereby, the ionic density in the lower ionosphere is increased over the daylight hemisphere producing radio fading and, in stronger cases, also a typical geomagnetic "eruption-effect" interpreted by McNish as a transitory increase of S. Only rarely, and only after the most intense eruptions, is this eruption-effect the precursor of a magnetic storm.

(6) These ideas suggest a hypothetical division of magnetic storms into two types: The front of a freshly formed stream of solar particles in sweeping across the Earth's orbit may either hit the Earth ("nascent-stream type") or not; in the latter case the rotating arm of the stream may overtake the Earth from the evening side ("mature-stream type"), as described by Chapman. The first particles may leave the Sun's surface at the time, t_s, and may have reached the Earth's distance (not necessarily in the Earth's orbit) at the time t_e. For "nascent" storms the travel-time $T=(t_e-t_s)$ can be calculated with t_s as the time of the eruption (either from direct solar observations, or from radio fade-outs, or from geomagnetic eruption-effects, all antedated by the travel-time, eight minutes, of light) and with t_e as the time of the outbreak of the magnetic storm.

An accurate determination of T is made difficult by the following circumstances: (*a*) Solar eruptions follow each other often within a few hours, which makes t_s indeterminate. (*b*) The Sun is not under a constant watch; even now great eruptions may pass unobserved. (*c*) The Earth may be already under the influence of smaller clouds from older M-regions, masking t_e by magnetic activity. (*d*) At the time of the sudden commencement of the storm, the cloud may, at other points, already have reached and passed the sphere drawn around the Sun with the Earth's distance as radius so that t_e should be assumed before the outbreak of the storm; otherwise T is overestimated. (*e*) The eruption sometimes lasts an hour and it is not certain when in that interval the particles first reaching the Earth's distance left the Sun.

The most favorable case is provided by a marked geomagnetic eruption-effect and a storm with a sudden commencement in an otherwise quiet time. Several authors have coordinated individual cases of

solar eruptions and magnetic storms but only a few cases of apparently "nascent" storms have so far been singled out in which T seems reasonably certain, namely: September 1-2, 1859, with $T=17^{h}\ 43^{m}$; January 16, 1938, with $T=22^{h}\ 3^{m}$; April 16, 1938, with $T=21^{h}$. It is hoped that a search of older magnetograms, now in progress, will reveal additional examples of this newly recognized eruption-effect. $T=20$ hours corresponds to an average travel-velocity of about 2000 km/sec.

(7) The fact emphasized by Greaves and Newton that great magnetic storms do not exhibit the 27-day recurrence-tendency now permits an interpretation differing from that which regards the solar eruption-source as exhausted in a single flare: It may be, namely, that the cone formed by the directions of the emitted particles is opened more widely at the first eruption than in the chain of the following weaker clouds forming the arm. This assumption supplements the picture of the arm by a preceding frontal shield; the most intense geomagnetic fluctuations lasting only a few hours are confined to the sweep of this shield across the Earth. If now the arm returns after a solar rotation it need not hit the Earth after 26 to 28 days because it either sweeps past the Earth to the north or the south without hitting it at all (especially in the early part of the sunspot-cycle, when sunspots are far away from the Sun's equator) or the arm hits the Earth after a somewhat indeterminate interval between 21 and 33 days, because the eruption-source has not been near the center of the Sun's disk. If, at the time of the commencement of a "nascent" storm, the Earth was located "before" the arm, the storm may last a few days or even be "revived" after a few days when the arm sweeps across the Earth, but if the Earth was "behind" the arm the "nascent" storm subsides soon. For both cases there are examples of storms which might be interpreted in this way. The puzzling individuality in the action of magnetic storms on cosmic radiation may be connected with this geometrical configuration, because the "ring-may be connected with this geometrical constellation, because the "ring-current" will be replenished differently in the two cases.

(8) The frequency of "nascent" storms may be estimated as follows: On the average the lifetime of an arm may be a, and there may be n arms existing simultaneously; this would mean that a new arm is formed at the average interval (a/n). w may be the central angle of the frontal "shield" or, more exactly, $(w/2\pi)$ may be the fraction of the Earth's orbit covered by it. The average interval of "nascent" storms is then $[(a/n)/(w/2\pi)]$; with $a=6$ solar rotations, $n=2$, $(w/2\pi)=1/4$, we obtain 12 solar rotations or roughly one year. The difficulties mentioned in section (6) limit still further the occasions for accurate determinations of travel-times T.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

LETTERS TO EDITOR

(See also pages 338 and 371)

MAGNETIC RESULTS IN CANADA

In accordance with Resolution 8, passed by the Association of Terrestrial Magnetism and Electricity at the Washington Assembly of the International Union of Geodesy and Geophysics, I have pleasure in sending you herewith the magnetic data obtained by this office in 1938 and 1939. It is expected that our publication containing the magnetic results for the years 1927 to 1937 will be ready for distribution this summer.

Station	Latitude, north		Longitude, west		Date	Declination, west		Incl'n, north		Hor. int.	Remarks
	°	′	°	′		°	′	°	′	γ	
Ottawa, *B**	45	5.0	75	42.5	1936.5	13	24.5	75	46.4	14245	Magnetic
					1937.5	13	22.2	75	47.6	14230	hut
					1938.5	13	22.3	75	48.2	14220	
Agincourt	43	47	79	16	1938.5	7	35.1	74	51.3	15310	Observato
White River, *C*	48	35.5	85	16.5	Jul 7- 9/38	5	25.6	78	05.8	12440	New
						East					
Twin City Jct., *A*	48	22.3	89	25.0	Jul 11-13/38	1	08.9	77	44.4	12847	Repeat
Twin City Jct., *C*	48	22.3	89	25.0	Jul 14-17/38	1	12.1	77	46.6	12830	New
Atikokan	48	45.3	91	37.1	Jul 19-22/38	3	30.4	77	29.7	13123	Repeat
Rainy River, *C*	48	43.3	94	35.0	Jul 23-25/38	7	25.6	77	23.2	13258	New
Winnipeg	49	51.9	97	07.7	Oct 3- 6/38	11	36.2	78	06.4	12643	Repeat
Brandon, *B*	49	52.0	99	59.0	Sep 28-30/38	12	52.9	77	29.3	13259	Repeat
Estevan	49	08.8	102	59.2	Jul 28-30/38	15	44.8	76	16.0	14360	Repeat
Assiniboia	49	38.2	105	59.1	Sep 23-25/38	17	36.1	75	47.4	14996	Repeat
Chaplin, *B*	50	28.0	106	39.5	Sep 19-21/38	19	09.6	76	37.6	14045	Repeat
Dunmore	49	58.5	110	35.6	Sep 15-17/38	20	23.0	75	24.1	15144	Repeat
Coronation	52	06.5	111	26.8	Aug 2, 3/38	22	40.4	76	31.7	14109	Repeat
Gleichen	50	52.2	113	03.3	Aug 22-24/38	22	52.1	75	27.6	15117	Repeat
Meanook	54	37	113	21	1938.5	25	54.8	77	52.7	12726	Observato
Lacombe, *A*	52	27.6	113	45.0	Aug 4- 6/38	24	23.9	76	25.1	14137	Repeat
Cranbrook, *C*	49	31.0	115	46.5	Sep 8-10/38	23	23.1	73	29.9	16762	Repeat
Prairie Point	58	15.6	116	28.6	Aug 11,12/38	32	22.6	79	43.2	10826	Repeat
Peace River	56	13.8	117	17.5	Aug 16-18/38	29	42.8	78	09.1	12413	Repeat
Jasper, *B*	52	53.5	118	04.0	Jun 21-23/39	25	58.6	75	28.7	14936	Repeat
Midway	49	00.5	118	46.8	Sep 4- 6/38	23	29.8	72	18.3	17686	Repeat
Sicamous, *B*	50	50.3	118	58.4	Aug 27-29/38	24	47.0	73	50.6	16354	Repeat
Penticton	49	49.3	119	35.5	Aug 31-S. 2/38	24	36.4	72	38.2	17481	Repeat
Kamloops, *C*	50	40.8	120	19.7	Jun 26-28/39	24	47.6	73	13.7	16720	Repeat
North Bend, *B*	49	52.7	121	25.8	Jn 29-Jy 1/39	24	57.2	72	28.5	17501	Repeat
Victoria, Mt., *D.*	48	29.1	123	19.0	Jul 4- 6/39	23	59.2	70	55.7	18613	Repeat
Smithers	54	46.7	127	09.3	Aug 19-21/39	28	45.5	74	56.6	15147	Repeat
Ocean Falls, *B*	52	21.3	127	40.3	Aug 11-15/39	26	25.1	73	07.2	16628	Repeat
Cape Scott	50	46.2	128	24.6	Jul 24-28/39	26	07.8	71	29.1	18245	New
Goose Island	52	00.2	128	24.9	Jul 17-19/39	26	23.9	72	00.2	17870	New
St. John Harbour	52	11.3	128	30.1	Jul 10-13/39	28	16.7	73	04.8	17041	New
Triangle Island	50	52.2	129	04.7	Jul 20, 21/39	26	03.3	71	17.1	18172	New
Prince Rupert	54	18.2	130	19.6	Aug 16-18/39	28	25.2	73	33.5	16223	Repeat

*Replaces original Ottawa station abandoned in 1938.

R. MELDRUM STEWART, *Dominion Astronomer*

DIVISION OF TERRESTRIAL MAGNETISM,
DOMINION OBSERVATORY,
Ottawa, Canada, June 18, 1940

GENERAL METEOROLOGICAL ASPECTS OF THUNDER-STORM ELECTRICITY

By Horace R. Byers

Physicists studying the details of lightning-discharges have in recent years progressed quite satisfactorily in analyzing the observed electrical phenomena. On the meteorological side, where the mechanism of the thunderstorm *as a cloud* in relation to the development of the strong potential-gradients which have been observed is to be investigated, the progress is, by comparison, relatively slight. It is the purpose of this paper to discuss some of these meteorological factors, particularly to bring them to the attention of the physicists as well as of the meteorologists who must work side by side in this field.

Measurements have shown that the potential-gradient, at least near the ground, is usually positive in fine weather or in the absence of thunderstorms and that this gradient is generally greatest at those times when the air is thermodynamically in a stable state of equilibrium and therefore not subject to the formation of thunder-showers. In the relatively weak gradients of convection-weather, however, as soon as a convection-cloud develops, the electrical field suddenly becomes very intense until, as the convection-cloud forms into a mature cumulo-nimbus,the phenomenal thunder-storm potentials appear.

It is at once obvious that the condensation-products that make up the cloud must be responsible for this sudden change in conditions and it seems to follow logically that the action of the convection-currents on these condensation-products plays an important rôle. On these elementary principles all workers on the problem appear to agree, but beyond them is almost chaotic disagreement as to the mechanism responsible. In fact, there appear to have been almost as many different theories as there have been investigators.

As examples, consider the two principal and, unfortunately, opposing theories that have dominated the literature for some years, namely those of Simpson and Wilson.

Simpson's breaking-drop theory, developed by him in various papers from 1908 to 1927[1] explains the lightning as caused by the action of vertical convection-currents on raindrops. According to this theory, the raindrop breaks up into a number of small drops by the force of the convection-current, the water becoming positively charged and the air negatively charged. Negative ions attach to the minute fog-like cloud-particles which are much smaller than the raindrops and are carried to the upper parts of the cloud by ascending currents, leaving the positively charged raindrops behind. Thus electrical separation takes place, the positive charge being concentrated in regions near the base of the cloud where rising motion can hold large quantities of water in suspension, and the negative electricity being distributed with the cloud-particles in the middle and upper parts of the cloud. This would

[1] Proc. R. Soc., A, **114**, 376-401 (1927).

produce a positive potential-gradient between the lower part of the cloud and the ground, and a negative gradient above. Simpson assumed that the lightning-discharge occurred between the positively charged lower region of large raindrops in the cloud and the ground, which seemed to agree with the fact that lightning occurs with heavy rain.

As additional evidence in support of his theory Simpson had observations which indicated that the greater part of the rain reaching the ground from a thunder-cloud brought down a positive charge. Also, the downward-branching of the lightning which is so commonly noted was thought to be possible, according to measurements in the laboratory, only in a positive discharge.

Schonland[2] and others working in South Africa found that a negative gradient between the ground and the thunder-cloud was very definitely the normal state of affairs during thunder-storms and it appeared that Simpson's theory could not possibly be confirmed. A weak negative gradient at the ground showed up in practically all measurements. A weakness in Simpson's arguments was also shown when Schonland demonstrated in the laboratory that branching could occur in a negative discharge if the potential-drop were of a sufficiently high order of magnitude. Furthermore, it was reasoned that the bringing down of a positive charge by raindrops was not proof in itself that a positive charge existed in the lower part of the cloud.

C. T. R. Wilson, in a paper presented before the Franklin Institute of Philadelphia in 1929[3] presented another theory of the development of the thunder-storm electrical breakdown which, as will subsequently be seen, was incomplete in certain minor respects, but nevertheless provided the pattern of charge-distribution in, under and around the thunder-cloud which is now shown to be essentially correct. His scheme indicates a bipolar thunder-cloud, positively charged in the upper part and negatively charged in the lower part. Thus, in agreement with the general indications of observations and measurements, he pictured a negative gradient between the cloud and the ground with a positive gradient between the upper and lower part of the cloud.

The mode of development of this type of charge-distribution as conceived by Wilson briefly is as follows:

Under fair-weather conditions there is a positive gradient. As the thunder-cloud develops, raindrops begin to fall out of the upper region of positive charge. These drops, due to the character of the field, have a negative charge induced on the upper half and a positive charge on the lower. If their speed of fall is greater than the downward descent of ions, the lower portion of each drop will tend to attract to it ions of opposite sign, that is, negative, and thereby to become negatively charged itself. Because of the speed of fall of the drop, positive ions from above cannot be drawn into the negatively charged upper surface and those from below would find difficulty in attaching themselves owing to repulsion as they flow around the lower part of the drop.

Thus the thunder-cloud represents the same field as in fair weather, only greatly intensified—so much so within the cloud, in fact, that the fair-weather positive gradient becomes reversed below the cloud.

It seems that Wilson's theory has weaknesses also. It does not

[2]Trans. S. Afric. Inst. Elec. Eng., **24**, part 6, 145-152 (1933).

[3]J. Frank. Inst., **208**, 1-12 (1929).

explain why lightning occurs only with strong convection. In other rain-situations reasonably large raindrops fall from the positively charged upper part of the cloud but without lightning phenomena. Violent convection does not make raindrops much larger than moderate convection, as there is a certain maximum size of drop above which the water cannot hold together. Therefore, it does not seem correct to say that only violent convection can make drops large enough to have a velocity of fall greater than the rate of descent of the ions.

These two theories (Simpson's and Wilson's) are the principal ones advanced to explain the thunder-storm electrical phenomena.

Simpson and Scrase[4] undertook measurements recorded from retrievable free balloons. They equipped the balloons with a pole finding device consisting of about 20 meters of vertical wire broken near the upper part and the two ends there attached to pins which dragged on a clock driven drum. This drum was treated with a certain electrochemically active substance which turned blue at whichever of these pins became the anode. For a positive gradient the coloration would occur at the pin leading from the upper part of the wire and for a negative gradient, from the lower lead-in. A simultaneous barograph record was included in the instrument for determining heights and a hygrograph-trace furnished some information concerning the limits of the clouds.

The balloon could not give the distribution of the electrical charge in the vertical at a given instant because of the time consumed in the ascent; nor did the balloon ascend vertically. These seemed to be serious difficulties at times, as there were some cases of important changes between ascents at 10-minute intervals.

Briefly, the results may be summarized by stating that in roughly two-thirds of the 37 cases of thunder-storm ascents there was indicated a positive charge in the upper part of the cloud and a negative charge in the lower part, in agreement with Wilson's model. In the remaining one-third of the cases the records again showed a positive charge in the base as well as at the top, the negative charge being elsewhere. From these results Simpson constructed a revised diagram of the distribution of charge in the thunder-storm, prescribing the same general picture as Wilson's except that a small region of positive charge exists in a portion of the cloud base.

A critical examination of the observations, particularly in the light of data collected by other observers, suggests that the one-third of Simpson's cases wherein there was a positive charge in a region of the cloud base may be fictitious. The main difficulty in the balloon method arises from the fact that changes with altitude in the charge-distribution cannot be separated from changes with horizontal distance or with time (particularly the latter). In nearly all of the cases where Simpson and Scrase reported a positive charge in the cloud-base, the field was changing at the ground with time and it appears reasonable that this same change with time could have been occurring in the cloud. Of 14 cases in which the balloon record was interpreted as indicating a distribution contradictory to the Wilson model, nine are doubtful because the field was changing at the ground and probably also changing with time in the cloud. In four cases the cloud was not overhead and it was not raining at the time of the observation. One case of a cold thunder-

[4] Proc. R. Soc., A, **161**, 309-352 (1937).

storm (0° C at 2.5 km) seemed to show that the positive gradient below the cloud was real.

Changes of the field with time are extremely important and make measurements from free balloons or airplanes doubtful as to their usefulness. Observations by Wilson[5], Banerji[6], and particularly by Workman and Holzer[7] show that a thunder-storm may go through a complete cycle of charging and discharging in about two minutes. The gradient below the cloud is negative until a cloud-to-ground lightning discharge occurs, when it jumps immediately to a positive gradient, following which a typical recovery or charging curve is shown, restoring the field to a negative potential again.

Of special interest in Simpson's work are his findings concerning the relation of distribution of charge to that of temperature (the latter obtained by assuming an appropriate lapse-rate). The following tabulation is taken from his paper:

	Average height in km
Upper positive charge	>4.6
Temperature of −10° C	4.3
Region of separation of upper charges	>3.9
Temperature of 0° C	2.9
Negative charge	2.7

From this it is apparent that the upper positive charge is centered in those parts of the cloud that are well below the freezing point while the main body of the negative charge is at a temperature above freezing.

Meteorologists have very good evidence that convection-clouds do not normally become thunder-clouds until the convection has penetrated into the ice-crystal level, as evidenced in the change in appearance of the top of a cloud as it develops from cumulus to cumulo-nimbus[8]. There is reason to believe that the precipitation starts in the upper part of the cloud and that this upper region continues to supply the major part of the rainfall. It would seem, then, that lower, positively charged drops, if they exist, would be relatively unimportant in thunder-storm precipitation. A relationship between thunder-storm electricity and ice-crystals due to the coexistence or existence in proximity of water in the liquid and solid phases is suggested.

Another interesting fact is that at the temperature around −10° C pilots have observed most displays of coronae or brush-discharges on airplanes and the greatest trouble with rain and snow static in the radio. Also, this is near the temperatures of greatest ice-formation danger on aircraft. There appears, therefore, to be an important "danger-zone" in convective clouds lying in the vicinity of the isotherm of −10° C where the strongest electrical potential exists (about midway between the centers of positive and negative charge). This zone is more subject to electrical discharges of all kinds, precipitation-static and ice-formation than any other portion of the cloud. The Bergeron theory of precipitation indicates that this zone is the critical one for the development of the more common forms of precipitation. This attaches new significance

[5]Phil. Trans. R. Soc., A, **221**, 73-115 (1920).

[6]Phil. Trans. R. Soc., A, **231**, 1-27 (1932).

[7]Paper before Amer. Phys. Soc., December 1938 (unpublished).

[8]T. Bergeron, On the physics of cloud and precipitation, Procès-Verbaux, Assemblée Générale, Lisbonne, 1933. Union Géod. Géophys. Internat., Ass., Mét., II, Mém. et Discussions, 156-172 (1935).

to the rôle of a heterogeneous mixture of water in the three phases—vapor, liquid, and solid. It leads to a picture of the thunder-cloud as in Figure 1.

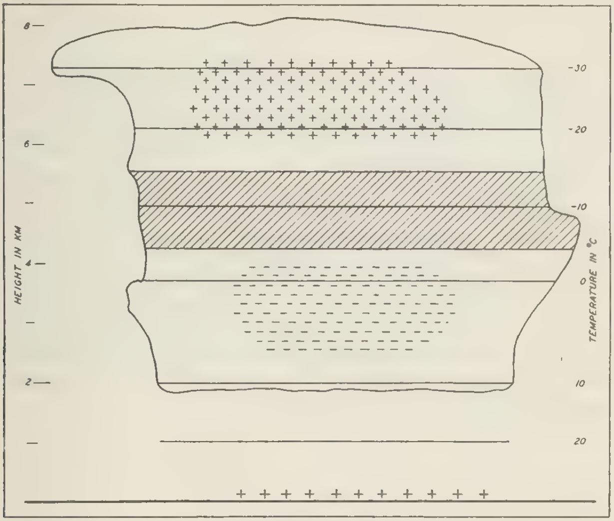


FIG. 1—IDEALIZED THUNDER-STORM CLOUD SHOWING TYPICAL TEMPERATURE-DISTRIBUTION FOR SUMMER CONDITIONS IN THE UNITED STATES AND LOCATION OF CHARGE-CENTERS [SHADED ZONE REPRESENTS REGION OF STRONGEST POTENTIAL-GRADIENT AND TRANSITION-ZONE FROM PREDOMINANTLY WATER TO PREDOMINANTLY ICE-CRYSTAL PORTION OF CLOUD; ALSO, THE REGION OF SERIOUS PRECIPITATION-STATIC, ELECTRICAL DISCHARGES, AND ICE-FORMATION ON AIRPLANES]

Conclusions

(1) The thunder-cloud consists, in accordance with Wilson's model, of a positively charged upper portion and a negative charge in the lower part.

(2) No wholly acceptable explanation of how the thunder-storm potential is built up has, in the author's opinion, yet been presented.

(3) The field beneath a thunder-cloud fluctuates in accordance with the lightning-discharges. The negative gradient near the ground jumps to positive momentarily after each discharge. These changes are so abrupt that only continuously recording instruments with a time-resolving power considerably less than a minute can show their nature.

(4) Changes in the field as noted in an ascending balloon may be changes with time instead of or as well as changes with altitude.

(5) As indicated by Simpson, the region of strongest positive gradient, which is about midway between the centers of positive and negative charge, is in the vicinity of the isotherm of $-10°$ C.

(6) Brush-discharges on airplanes and radio interference from clouds (precipitation-static) are observed by pilots to be most pronounced in the levels of the clouds near the isotherm of $-10°$ C. This is also a region of ice-formation hazard.

(7) At the $-10°$ C-isotherm is the probable transition from liquid to ice-crystals as the predominating cloud-elements.

(8) *Thunder-storm potential-gradients result from processes involving liquid water-particles in close proximity to ice-crystals.* Reasonable evidence has already been presented by Bergeron to prove that ice-crystals are essential for appreciable precipitation. The conclusion is that they also play an essential rôle in the generation of thunder-storm electricity.

(9) The theory predicts that in a newly forming thunder-storm no strong potentials exist until the thunder-heads penetrate to the ice-crystal level. The first lightning-discharge would be within the upper portion of the cloud between the positive and negative regions, followed later by cloud-to-ground strokes.

[Note by author: While this article was in press, Dr. Workman, in a paper before the American Meteorological Society, Kansas City, Missouri, June 15, 1940, presented results indicating a vertical separation of less than one km between the charge-centers in the cloud. This would require a modification of Figure 1, bringing the positive and negative charge-centers just within the upper and lower parts, respectively, of the shaded zone. His results indicate also that in the later life of a thunder-storm the main gradients may become horizontal, apparently due to the transport of charges by the convection-currents.]

U. S. Weather Bureau,
Washington, D. C.

THE MAGNETIC CHARACTER OF THE YEAR 1939 AND THE NUMERICAL MAGNETIC CHARACTER OF DAYS, 1939

By G. van Dijk

The annual review of the "Caractère magnétique de chaque jour" for 1939 has been drawn up in the same manner as for the preceding years.[1] Sixty-two observatories contributed to the quarterly tables; fifty-three of them sent complete data.

In the introduction a note has been inserted concerning the publication "Caractère magnétique numérique des jours" for 1939, volumes XXX-XXXIII have been published along with the tables of "Caractère magnétique de chaque jour."

Forty observatories have sent lists for 1939, thirty-seven of them were complete.

Table 1—*Mean magnetic character-numbers for each day of 1939 from data supplied by observatories*

Month	Dates														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1939															
January	0.1	0.3	0.1	0.2	1.0	0.7	0.6	0.8	1.0	0.8	0.7	0.4	0.2	1.0	0.4
February	1.3	1.2	0.9	0.5	1.0	1.8	1.2	0.6	0.9	1.1	0.8	0.0	0.3	0.5	1.0
March	1.4	1.3	1.2	1.3	0.8	0.7	0.4	0.9	1.1	0.6	1.0	0.9	0.4	0.5	1.1
April	1.2	1.0	0.9	1.1	0.8	0.2	0.2	0.8	1.0	1.4	1.4	1.0	0.5	0.5	0.2
May	1.8	1.5	1.0	0.5	1.4	1.6	1.5	1.4	1.2	0.4	0.2	0.2	0.4	0.1	0.5
June	0.9	1.2	1.0	1.1	0.7	0.3	0.2	0.2	0.0	0.5	0.2	0.2	1.0	1.8	0.7
July	0.7	0.6	1.7	1.7	2.0	0.8	0.1	0.3	0.2	0.1	1.0	0.9	0.2	1.4	0.7
August	0.2	0.0	0.1	0.3	0.1	0.1	0.1	0.3	0.1	1.1	1.1	2.0	1.4	0.5	0.3
September	0.2	0.9	1.5	0.4	0.2	0.4	0.4	0.4	1.4	1.0	0.3	0.7	0.4	0.7	0.3
October	0.6	0.3	1.7	1.6	1.2	1.3	0.9	0.6	1.4	0.3	0.7	0.1	2.0	1.9	1.8
November	0.5	0.2	0.5	0.2	0.3	0.4	0.4	0.1	0.2	0.1	0.5	0.9	1.6	1.1	0.7
December	0.6	0.4	0.5	0.3	1.0	1.3	1.8	1.4	1.1	0.7	0.3	0.7	0.3	0.2	0.4

Month	Dates																Means
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1939																	
January	0.7	1.0	0.5	0.4	0.6	1.1	1.0	0.8	0.5	0.2	0.0	0.0	0.4	0.3	0.1	0.2	0.51
February	1.1	1.1	0.9	0.9	0.5	0.1	0.2	0.6	2.0	1.9	0.5	0.3	0.9				0.86
March	1.1	0.7	0.2	0.3	0.5	1.3	1.5	1.1	0.8	0.4	0.8	1.4	1.8	1.9	1.4	1.0	0.96
April	0.4	2.0	1.6	1.6	1.2	1.1	1.2	1.9	1.9	1.7	0.5	0.9	0.8	0.7	0.5		1.01
May	1.1	0.7	0.7	0.8	0.7	1.2	1.2	1.3	1.2	1.2	0.9	0.7	1.1	1.4	0.3	0.2	0.93
June	1.3	0.3	1.2	1.2	0.9	1.1	0.7	0.7	0.4	0.2	1.0	1.2	1.0	1.2	0.9		0.78
July	1.2	1.1	0.5	0.9	1.6	1.7	1.1	0.6	0.6	0.8	1.5	0.8	0.5	0.3	0.2	0.2	0.83
August	1.8	1.1	0.4	1.0	0.4	0.8	2.0	1.9	0.9	0.5	0.4	0.4	0.3	0.3	0.6	0.2	0.66
September	0.4	1.7	0.5	1.4	1.4	0.6	0.8	0.2	0.2	0.8	1.2	0.4	0.1	0.1	0.8		0.66
October	1.5	1.3	1.3	1.0	0.2	0.8	0.5	1.0	0.4	0.2	0.4	0.1	0.6	0.5	0.5	0.3	0.87
November	0.2	0.3	0.1	0.8	0.3	0.2	0.1	0.1	0.8	1.2	1.0	0.4	0.3	0.5	0.3		0.47
December	0.7	0.3	0.0	0.0	0.2	1.3	1.3	0.8	0.6	0.3	0.2	1.0	0.7	0.6	0.4	0.1	0.63
																	0.763

[1]Terr. Mag., **33**, 203 (1928); **34**, 207 (1929); **35**, 178 (1930); **36**, 255 (1931); **37**, 259 (1932); **38**, 301-302 (1933); **39**, 237-238 (1934); **40**, 383-384 (1935); **41**, 351-352 (1936); **42**, 395-396 (1937); **43**, 471-472 (1938); **44**, 391-393 (1939).

Table 2—*Dates of five magnetically calm and five disturbed days with mean character-numbers during*

Month	Calm days						Disturbed days				
1939											
January.....	(0.08)	**1,**	**3,**	**26,**	**27,**	**30**	**5** (1.0),	**9** (1.0),	**17** (1.0),	**21** (1.1),	**22**
February....	(0.17)	**12,**	**13,**	**21,**	**22,**	**27**	**1** (1.3),	**6** (1.8),	**7** (1.2),	**24** (2.0),	**25**
March......	(0.36)	**7,**	**13,**	**18,**	**19,**	**25**	**22** (1.5),	**27** (1.4),	**28** (1.8),	**29** (1.9),	**30**
April.......	(0.30)	**6,**	**7,**	**13,**	**15,**	**16**	**17** (2.0),	**18** (1.6),	**23** (1.9),	**24** (1.9),	**25**
May........	(0.24)	**11,**	**12,**	**13,**	**14,**	**31**	**1** (1.8),	**2** (1.5),	**6** (1.6),	**7** (1.5),	**8**
June........	(0.16)	**7,**	**8,**	**9,**	**11,**	**25**	**14** (1.8),	**16** (1.3),	**19** (1.2),	**27** (1.2),	**29**
July........	(0.14)	**7,**	**9,**	**10,**	**13,**	**30**	**3** (1.7),	**4** (1.7),	**5** (2.0),	**20** (1.6),	**21**
August......	(0.07)	**2,**	**3,**	**5,**	**6,**	**7**	**12** (2.0),	**13** (1.4),	**16** (1.8),	**22** (2.0),	**23**
September...	(0.17)	**1,**	**5,**	**24,**	**28,**	**29**	**3** (1.5),	**9** (1.4),	**17** (1.7),	**19** (1.4),	**20**
October.....	(0.18)	**12,**	**20,**	**25,**	**27,**	**31**	**3** (1.7),	**4** (1.6),	**13** (2.0),	**14** (1.9),	**15**
November...	(0.11)	**8,**	**10,**	**18,**	**22,**	**23**	**12** (0.9),	**13** (1.6),	**14** (1.1),	**25** (1.2),	**26**
December...	(0.09)	**14,**	**18,**	**19,**	**20,**	**31**	**6** (1.3),	**7** (1.8),	**8** (1.4),	**21** (1.3),	**22**

Days recommended for reproduction are:

**February 24; August 22; October 13.

*March 28; April 17 and 24; May 6; July 5; August 12; October 3.

Meteorologisch Instituut,
De Bilt, Utrecht, Holland, May 1940

MULTIFREQUENCY RECORDINGS OF RADIO-WAVE POLARIZATION NEAR THE GEOMAGNETIC EQUATOR

By H. W. Wells

Abstract—Theory of radio-wave propagation predicts that in the special case of propagation of a wave in the ionosphere with its wave-normal perpendicular to the Earth's magnetic field at all points along the wave-path, the two wave-components returned should be plane-polarized in mutually perpendicular planes. The Huancayo Magnetic Observatory (Peru) of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, is suitably located for special polarization-tests under the conditions above outlined since the inclination of the Earth's magnetic field is only some 2° 14′ from the horizontal. Earlier tests at this location in 1935 confirmed the general theory for propagation in the F-, F_1-, or F_2-regions. It was shown that a simple doublet antenna oriented in magnetic north-south plane would record only the ordinary wave-component; while an antenna in the magnetic east-west plane would record only the extraordinary wave-component. Recent tests made with automatic multifrequency apparatus are found to be in complete agreement with earlier results, and evidence is presented which warrants extension of earlier conclusions to include E-region propagation under certain conditions.

Historical—As early as 1878, Balfour-Stewart [see 1 of "References" at end of paper] postulated the existence of a conducting stratum in the upper atmosphere as a necessary condition to his theory of diurnal variation of the Earth's magnetic field. In 1902, A. E. Kennelly [2] and O. Heaviside [3] independently proposed the existence of such a stratum to explain Marconi's success in sending wireless signals from England to Newfoundland. They suggested that an ionized medium above the Earth might deflect radio waves and cause them to be sent back to Earth. Lorentz's theory of electrons [4] was applied to propagation of electromagnetic waves in an inhomogeneous ionized medium by Eccles [5] in 1912 to explain the mechanics of radio-wave refraction. This treatment was extended by Larmor [6] in 1924 who drew attention to the fact that free electrons would be far more effective than ions for the bending of electromagnetic waves. Appleton [7] suggested that the Earth's magnetic field would modify the simple formula. However, direct evidence of the existence of the ionosphere was lacking until the investigations of Breit and Tuve [8] in 1925. Almost simultaneously, Appleton and Barnett [9] reported similar evidence obtained by an independent method.

The influence of the Earth's magnetic field on radio-wave transmission was extended by Schelleng and Nichols [10], Taylor and Hulburt [11], Breit and Tuve [8], Pedersen [12], and others. It was shown that electromagnetic waves propagated in a magnetic field should be split into two components, in general elliptically polarized in opposite senses and traveling with different velocities in the ionized medium. Only the special cases involving propagation along and at right-angles to the magnetic field were considered in any detail. It was generally agreed that for propagation along the magnetic field the incident wave should be split up into two waves both circularly polarized but in the opposite senses; while for propagation at right-angles to the field, the incident wave should be resolved into two plane-polarized components. For the

latter case the ordinary wave-component would have its electric vector parallel to the plane of the Earth's field, while the extraordinary component would have its electric vector perpendicular to the magnetic plane.

For the condition of propagation at right-angles to the field the solutions for the returned wave are of the form

$$Y = Y_0 \epsilon^{i\omega[t - u_1(x/c)]} \text{ (extraordinary)} \quad (1)$$

$$Z = Z_0 \epsilon^{i\omega[t - u_2(x/c)]} \text{ (ordinary)} \quad (2)$$

These are readily interpreted as states of plane-polarization. This basic condition may be reproduced experimentally by means of vertical-incidence transmission and reception of radio signals at the magnetic equator. Here propagation with the wave-normal perpendicular to the Earth's magnetic field and to the iso-ionic surfaces of the ionosphere is possible throughout the wave-path.

Polarization tests of 1935—The condition outlined above is approximated at the Huancayo Magnetic Observatory in latitude 12° 02′.7 south and longitude 75° 20′.4 west. At this location the magnetic inclination is 2° 14′ north, that is, the field is inclined 2° 14′ from the horizontal. Results of experiments conducted here in 1935 to test the applicability of the theoretical conclusions were reported by Wells and Berkner [13]. Illustrations of photographic recordings on a fixed frequency and of manually observed and manually operated multifrequency observations of virtual height against frequency were presented for different orientations of antennas. The authors arrived at the following experimental conclusions for an electromagnetic wave propagated into the F-, F_1-, or F_2-regions of the ionosphere with the wave-normal perpendicular to the Earth's magnetic field and to the iso-ionic surfaces throughout its path:

(1) Two wave-components, o and x, are returned because of magneto-ionic double refraction.
(2) The o wave-component is plane polarized in a magnetic north-south plane.
(3) The x wave-component is plane polarized in a magnetic east-west plane.
(4) The reduction in refractive index of the medium is greater for the x wave-component for a given density of free charge in accordance with the simple theory; in this respect, no deviations from the general theory such as might be attributed to dissipation, ground-reflection, etc., were observed within the limits of precision of the experiments.
(5) The o and x wave-components are returned with approximately the same amplitude.
(6) When the wave is subject to very great group-retardation, as is the case at a critical frequency, the polarization of each wave-component becomes somewhat elliptical.

The authors pointed out that these general conclusions are all in direct confirmation of the simple theory *within the limits* of the experiments.

Polarization tests of 1940—A powerful tool for extension of ionospheric investigations became available with the development by Berkner,

Wells, and Seaton [14] of automatic multifrequency equipment for continuous photographic recording of radio reflections over a frequency-range from 16.0 to 0.516 mc/sec. The first unit of this type was installed at Huancayo in 1937 [15]. Operation since then has been continuous on a 24-hour day basis except for short intervals necessary for maintenance of the equipment, and quarterly tabulations of average results are published in each issue of this JOURNAL.

In January, 1940, additional polarization-recordings were conducted with the new multifrequency equipment for the purposes of testing earlier conclusions obtained with simpler apparatus, and of extending the results to a wider frequency-range. The short antenna shown in Figure 1 transmits the radio pulses and receives the reflections automatically over a frequency-range from 16.0 to 3.3 mc/sec, while the lower frequencies require the use of an additional antenna which is much longer. This short antenna was made rotatable so that it could

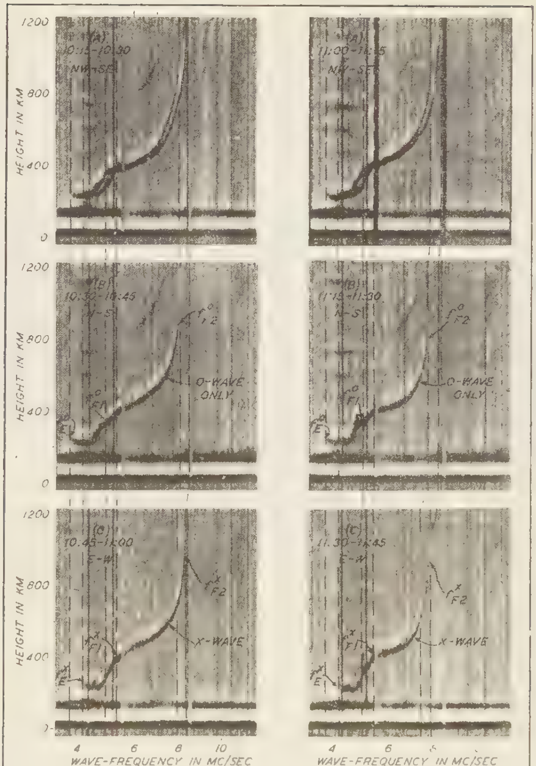


FIG 2 FIG 3

FIGS. 2 & 3—POLARIZATION TESTS WITH ROTATABLE ANTENNA, HUANCAYO MAGNETIC OBSERVATORY, JANUARY 11, 1940, 75° WEST MERIDIAN HOURS (ANTENNA ORIENTATION WITH RESPECT TO EARTH'S MAGNETIC FIELD: N-S, NORTH-SOUTH; E-W, EAST-WEST; NW-SE, NORTHWEST-SOUTHEAST)

be oriented in any desired direction. (One should bear in mind that, according to the theory outlined, a simple north-south antenna at this location should respond only to the *o* wave-component, while an east-west antenna should respond only to the *x* wave-component.) Antennas are normally oriented in a northwest-southeast direction so as to give equal response to both wave-components.

Figures 2 and 3 give reproductions of normal recordings with the antenna in a northwest-southeast direction. Critical frequencies for both wave-components for the E-, F_1-, and F_2-regions are indicated at the intersections of the three pairs of parallel vertical lines with the photographic recordings of virtual height against frequency. Scales of wave-frequency in mc/sec, and of virtual height in km are indicated on the Figures. Note that both wave-components are clearly visible for all three ionospheric regions. The three groups of vertical parallel lines

on each Figure indicate the penetration-frequencies for the E-, F_1-, and F_2-regions.

Figures 2 and 3 show recordings also at intervals immediately following under exactly similar operating conditions except that the antenna-orientation is in the magnetic north-south plane. Note the complete disappearance of any trace of the x wave-component, leaving a recording of the o wave, alone.

Figures 2 and 3 illustrate also recordings at intervals immediately following those for orientation of antennas in magnetic north-south plane but with antenna oriented approximately in the magnetic east-west plane. Note the complete disappearance of the o wave-component from the E-region, and the strong discrimination against the o wave in the F_1- and F_2-regions, essentially leaving a recording only of the x wave-component. In view of the conclusive results we may presume that the weak appearance of the o wave on the east-west antenna can probably be attributed to difficulty in exactly orienting the antenna and to a slight ellipticity of polarization due to the magnetic dip of 2° at this location.

Conclusions—These results confirm the general conclusions from the results of 1935 and the simple theory as outlined above for a wave propagated into the F-, F_1-, or F_2-regions of the ionosphere with the wave-normal perpendicular to the Earth's magnetic field and to the iso-ionic surfaces throughout its path. The wider range and more powerful method of these investigations make it possible to extend these same general conclusions to include the E-region, as well. The recordings indicate that the process of radio-wave refraction in the E-region is primarily electronic in nature. The simple formula assumes that the wave-frequency is large with respect to the frequency of collisions between electrons and gas molecules. These results show the simple formula– and hence the assumption as to collisional frequency – to apply to the E-region at heights of just above 100 km for E-region critical frequencies somewhat less than 4 mc/sec.

Acknowledgment—The author expresses appreciation to W. Culmsee and R. C. Coile of the staff of the Huancayo Magnetic Observatory for assistance with the experiments, to L. V. Berkner for helpful suggestions, and to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, whose active support and interest have made possible the development and operation of the automatic multifrequency ionospheric equipment.

References

[1] Balfour Stewart, Encyclopaedia Britannica, 9th ed., **16**, 159-184 (1878). [The date appearing on the title-page of the volume is obviously in error; internal evidence in the article indicates that the date should be 1882 or 1883.]
[2] A. E. Kennelly, Elec. World Eng., **39**, 473 (1902).
[3] O. Heaviside, Encyclopaedia Britannica, 10th ed., **33**, 213-218 (1902).
[4] H. A. Lorentz, The theory of electrons and its applications to the phenomena of light and radiant heat, Leipzig (1909).
[5] W. H. Eccles, Proc. R. Soc., A, **87**, 79-99 (1912).
[6] J. Larmor, Phil. Mag., **48**, 1025-1036 (1924).
[7] E. V. Appleton, Proc. Phys. Soc., **37**, 16D-22D (1925).
[8] G. Breit and M. A. Tuve, Phys. Rev., **28**, 554-575 (1926).
[9] E. V. Appleton and M. A. Barnett, Proc. R. Soc., A, **109**, 621-641 (1925).

[10] H. W. Nichols and J. C. Schelleng, Bell System Tech. J., **4**, 215-234 (1925).
[11] A. H. Taylor and E. O. Hulburt, Phys. Rev., **27**, 189-215 (1926).
[12] P. O. Pedersen, The propagation of radio waves along the surface of the Earth and in the atmosphere, Chapter 6, Copenhagen (1927).
[13] H. W. Wells and L. V. Berkner, Terr. Mag., **41**, 75-82 (1936).
[14] L. V. Berkner, H. W. Wells, and S. L. Seaton, Trans. Edinburgh Meeting, 1936; Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, 340-357 (1937).
[15] H. W. Wells and H. E. Stanton, Terr. Mag., **43**, 169-171 (1938).

Huancayo Magnetic Observatory,
Huancayo, Peru, June 13, 1940

THE MAGNETIC STORM OF MARCH 24, 1940

By A. G. McNish

Disturbance of electric power-systems during the great magnetic storm of March 24, 1940, has created a new interest in the study of geomagnetic phenomena. Operation of telegraph-instruments by electric currents induced by geomagnetic changes was observed shortly after the art of wired telegraphy had been introduced, and the effects of magnetic disturbances on the ionosphere, and consequently on radio transmission, were recognized with the advent of short-wave transmission. But there have never been any previous reports of interference with power-transmission. Clearly, only the most violent of magnetic storms are capable of affecting power-systems for none of the other great storms of the present sunspot maximum gave rise to noticeable effects. Nor were any power-line troubles experienced during the great storm of May 13-16, 1921.

"Was this storm of March 24, 1940, the greatest of all times?" is a question which arises from consideration of these facts. With regard to duration of intense activity the storm of May 13-16, 1921 which probably consisted of several storms in rapid succession—stands out as the greatest of all time, but greater ranges were recorded during the storms of April 16, 1938, and of March 24, 1940. Large ranges were observed during a number of other great storms but since the limits of the recording instruments were exceeded in a number of those cases definite values cannot be assigned (see Table 1, part of which is reproduced from *Geomagnetism* by S. Chapman and J. Bartels). Another factor which should be considered in rating the "greatness" of a magnetic

TABLE 1—*Great magnetic storms*

Date	Ranges*			Station	Remarks
	Declination	Horizontal intensity	Vertical intensity		
	′	γ	γ		
9, Aug. 28-Sep. 7	140	700(?)	400(?)	Greenwich, England	Telegraphic service greatly disturbed
2, Feb. 4	...	> 960	....	Bombay, India	Aurora seen at Bombay
2, Nov. 17-21	115	>1090	>1060	Greenwich, England	Largest sunspot-group of that cycle on Sun
3, Oct. 31-Nov. 1	186	> 950	> 950	Potsdam, Germany	
9, Sep. 25	210	>1500	>1100	Potsdam, Germany	Lasted only about 10 hours
	68	800	235	San Juan, Puerto Rico	
1, May 13-16	199	1060	1100	Potsdam, Germany	Aurora seen at Samoa
	>120	> 800	>1000	Cheltenham, Maryland	
	96	>1100	453	Watheroo, Western Australia	
8, Apr. 16	328	1900	600	Potsdam, Germany	Lasted only about 10 hours
	25	1320	118	Huancayo, Peru	
	291	>1[illegible]0	1020	Cheltenham, Maryland	
0, M 24-25	135	2300	900	Potsdam, Germany	Disturbance of power-circuits in North America
	137	850	1100	Cheltenham, Maryland	
	21	1390	122	Huancayo, Peru	
	45	690	....	Watheroo, Western Australia	

*Expressed in minutes of arc for declination and in γ (1γ = 0.00001 gauss) for horizontal and vertical components.

storm is the maximum rate of change of the magnetic field. Although satisfactory observations of this factor are not obtained directly it may often be inferred from other observations. If this feature is taken as a measure of the greatness of a magnetic storm, then that of March 24, 1940, probably stands preeminent in the annals of terrestrial magnetism.

The magnetograms of this storm are, in most cases, unsatisfactory for detailed analysis owing to the rapidity of motion of the recording spots and the limited range of most magnetographs [see 1 under "References" at end of paper], but from the records which are available and from numerous collateral data interesting conclusions may be derived.

The most striking feature of this storm was its effect on electric power-lines. When reports of power-line disturbances were first received both magneticians and electric engineers were inclined to disbelieve that the storm was responsible for the disturbances. But the accumulated evidence for the connection between the storm and the power-line disturbances soon became convincing. First, the disturbances were reported from a number of electrically isolated systems in the United States and Canada, and second, the effects all occurred at the same time which was also the time of onset of the severest part of the storm, about $16^{h}\ 40^{m}$ GMT.

A compilation of the power-system effects reported during the storm and an analysis of them has been prepared by W. F. Davidson, Director of Research, Consolidated Edison Company of New York, Inc. [2]. A survey of 22 power-companies located in various parts of the United States and Canada reveals that disturbances were experienced in the New England States, New York, Eastern Pennsylvania, Minnesota, Quebec, and Ontario. No trouble was reported from the southern and western parts of the country. Following Mr. Davidson's report, the power-disturbances fall into two principal classes—those in which transformers were thrown out of service by functioning of the protective relays or blowing of fuses and those in which large reactive power-surges were observed.

All of these effects may be explained by the presence of large direct currents in the alternating-current lines. Customary electric-engineering practice employs relays to protect large transformers. In case the currents in the primary and secondary windings of a transformer depart from a certain ratio the relay throws the transformer out of operation. Usually these relays are inductively coupled to the power-lines so that a direct current in either the primaries or secondaries would not directly operate the relays. However, a large direct current in a transformer may partially or completely saturate the iron core and disturb the balance between the primary and secondary currents and thus cause the relay to function. Transformers are designed so that the self-inductance of the primary is sufficient that the counter-electromotive forces approximately balance the impressed-electromotive forces when no current is flowing in the secondary. Saturating the iron core by means of a direct current effectively lowers the self-inductance of the primary. When this condition exists larger alternating currents must flow in the primary, known as magnetizing currents, in order to build up sufficiently strong counter-electromotive forces. All of the effects observed appear to be explainable on this basis.

Several specific cases of power-system disturbance are of interest. The Newberryport-Haverhill (Massachusetts) 22-kilovolt line of the New England Power Company was carrying an alternating current of about eight amperes during the morning of March 24 approximately the charging current of the line, that is the current necessary to produce the counter-electromotive forces in the transformers when no load is being drawn. When the storm began surges as great as 60 amperes alternating current were observed—being somewhat more than the normal full-load current. These surges, of course, represent the increased charging current of the line due to lowered effective inductance of the transformers through the direct currents produced by the storm.

After a transformer-bank of the New England Power Service Company in Providence (Rhode Island) had been tripped out by operation of a differential relay an ammeter was put into the transformer-neutral which recorded a direct current of 25 amperes. While this current was recorded no further difficulties were experienced in operation, implying that the direct current responsible for the disturbance was considerably in excess of this amount.

A quantitative analysis of the disturbances observed on the New York system of the Consolidated Edison Company of New York has been made by Mr. Davidson. These disturbances consisted of dips of voltage and coincident increases in the reactive loads without any appreciable changes in the actual power-loads. Using test-data on transformers of the type involved and taking into account the length of the grounded transmission-lines he calculated that the observed effects could be produced *provided the direct-current potentials produced by the magnetic storm were ten volts per mile.*

There are a number of other significant facts concerning the disturbances on power-systems. The surges noted had a duration of about a minute in most cases. A number of operations of the automatic oscillograph occurred at the Lockport Station of the Niagara Hudson Power Corporation. These records showed a distorted wave-form such as would be produced by a transformer with a superposed direct current. There was no evidence of alternating currents of the approximate frequency of industrial currents on these oscillograms; in fact, none of the observations on any system suggests that the currents produced by the storm were alternating currents in the common sense. No difficulties were experienced with three-phase transformers of the core-type, that is, those in which magnetomotive forces produced by direct currents in the three legs are in opposition.

Strong disturbances of radio and wire-communication were experienced during the storm although no novel effects were noted. Radio communication between North America and Europe was practically impossible on direct paths for the remainder of the day after the beginning of the storm, although channels between North and South America were but slightly affected. The transmission-disturbance figure of the Bell Telephone Company for March 24, 1940, was the highest which had ever been obtained.

Interference with wire-communications was the greatest which had been experienced since the great storm of May 13-16, 1921, when interruptions to service occurred about to the same extent as during the recent

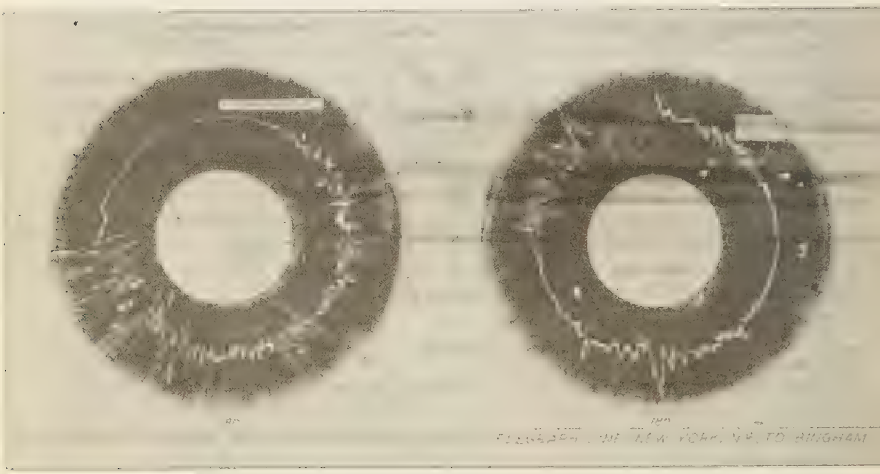
storm, according to a report by L. W. Germain, General Plant Manager of the Long Lines Department of the American Telephone and Telegraph Company [3].

The greater part of the communication-system operates on a full metallic basis although a large number of lines still employ the Earth to act as one of the conductors. These earthed lines were naturally most severely affected. Usually these lines could be operated by combining two of them and thus producing full metallic circuits, although this procedure diminishes the effective number of circuits by a factor of two.

Failures of long-distance telephonic land-circuits for the entire United States did not exceed ten per cent, since severe effects were experienced only in certain regions. At one time during the storm about 80 per cent of the long-distance lines out of Minneapolis (Minnesota) were out of service while 200 long-distance lines out of Chicago were unusable between 17^{h} and 19^{h} GMT.

The telephotographic network which serves 30 cities in the United States with press-photographs was also affected but nevertheless 60 per cent of the normal number of pictures was handled. In a large number of the pictures transmitted minor distortions due to the magnetic storm could be noted.

When it became obvious that a great magnetic storm was in progress recording voltmeters were inserted in a number of telegraphic and telephonic circuits. These instruments recorded unusually high earth-potentials. On the 140-miles line of the Western Union Telegraph Company between New York (New York) and Binghamton (New York) potentials of 800 volts were recorded (see Fig. 1). This is a gradient of



approximately six volts per mile which may be compared with the gradient of ten volts per mile required for producing the effects observed on power-systems. It may be that even greater voltages occurred on this line but were not recorded since 800 volts is the maximum range of the instrument.

These various effects are clear evidence that the magnetic storm of March 24, 1940, produced potential-gradients in the Earth amounting to about ten volts per mile, or six volts per kilometer. Although high earth-resistivity along the path of the natural earth-currents enhances the potential-differences observed for short paths, the major portion of this gradient must be due to direct induction by the varying magnetic field. Calculation of the field-changes necessary to produce these currents is readily accomplished.

We may assume that the principal effects were due to fluctuations of current along the auroral zone which during this storm was displaced considerably to the south. The electromotive forces **E** may be calculated from the vector-potential **A** of the auroral-zone currents by the equation

$$\mathbf{E} = \mathrm{d}\mathbf{A}/\mathrm{d}t = \mathrm{d}\left[\int (\mathbf{I}/r)\mathrm{d}\mathbf{s}\right]/\mathrm{d}t$$

in which **I** is the current flowing along the auroral zone, r its distance from the point for which the vector-potential is calculated and **s** a vectorial element of length along the path. Assuming that the path of the current is at a height of 200 km and extends for a distance of 2500 km in an east-west direction, we obtain a maximum value of **E** in an east-west direction of five emu per cm for a unit-variation of current, neglecting the return-circulation which may be considered as diffuse. If the current-fluctuation is 12,000 amperes per second this amounts to ten volts per mile or six volts per kilometer. In this calculation the effects of induced currents were neglected.

Magnetic changes due to such fluctuations of the current amount to 12 gammas per second in horizontal intensity immediately beneath the current, and since the evidence shows that large potentials continued for about 30 seconds, sudden changes in the magnetic field in the neighborhood of 400 gammas must have occurred. Records from magnetic observatories close to the auroral zone are too unsatisfactory to reveal whether or not such changes did occur, but study of the Agincourt records for the storm shows that changes as great as 180 gammas in one minute occurred in vertical intensity. Since the records indicate that the auroral zone was almost directly above Agincourt during the severest part of the storm it is reasonable to suppose that such changes did occur in horizontal intensity although they could not be measured since the movements were too rapid and too great to be recorded. A map for the distribution of electromotive forces in the eastern United States for an assumed current-fluctuation of 15,000 amperes per second together with indications of power-system and communication-system disturbances is presented in Figure 2.

Unusual but not unprecedented visible auroral activity accompanied the storm. A large active sunspot-group had just developed on the Sun a few days before the storm, but this group was not of unusual proportions.

Thus the great magnetic storm of March 24, 1940, has left a vivid impression on the minds of power- and communication-engineers and even on the minds of the public, many of whom failed to hear their favorite radio broadcasts because of its effects; but it has left only an indecipherable jumble on the photographic records of many of the World's magnetic observatories. It has accomplished effective missionary

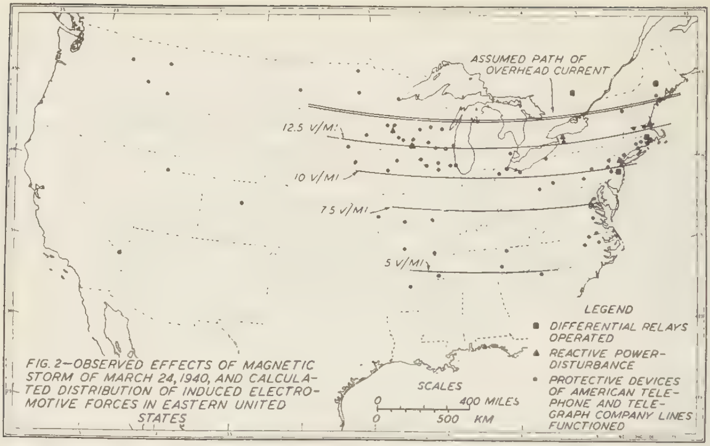


FIG. 2—OBSERVED EFFECTS OF MAGNETIC STORM OF MARCH 24, 1940, AND CALCULATED DISTRIBUTION OF INDUCED ELECTROMOTIVE FORCES IN EASTERN UNITED STATES

work in emphasizing the need of wide-range magnetographs at the principal magnetic observatories. Three such magnetographs were set into operation shortly after the storm and installation of additional ones is projected [4, 5, 6].

References

[1] J. A. Fleming, Sci. Mon., **50**, 475-480 (1940). For detailed account of this storm at various observatories and reproduction of magnetograms see Terr. Mag., **45**, 226-234 and 235-236, (1940).
[2] Edison Elec. Inst. Bull., **8**, 365-366, 374 (1940).
[3] Edison Elec. Inst. Bull., **8**, 367-368 (1940).
[4] J. A. Fleming, Terr. Mag., **45**, 213-214 (1940).
[5] J. H. Nelson, Terr. Mag., **45**, 371-372 (1940).
[6] H. Spencer Jones, Terr. Mag., **45**, 371 (1940).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., August 5, 1940

FINAL RELATIVE SUNSPOT-NUMBERS FOR 1939 AND MONTHLY MEANS OF PROMINENCE-AREAS FOR 1931-1939

By W. Brunner

Table 1 contains the final sunspot-numbers for 1939, for the whole disk of the Sun, based on observations made at the Zürich Observatory,

Table 1—*Final relative sunspot-numbers for the whole disk of the Sun for 1939*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	41	79*	102^{ad}	E 34^{c}	E163^{c}	129	103	E 67^{cd}	103^{ab}	144^{ad}	E 81^{aacd}*	54^{d}
2	42*	M 90^{c}	92	M 85^{c}	157^{aad}	120^{a}	97^{a}	78	116^{d}	143^{a}	88*	40
3	60*	97^{ad}	70	83	119*	113^{ad}	112^{dd}	M 73^{aac}	124	109*	72	43
4	M 76^{ac}	67	75	82^{a}	141	97^{a}	E128^{c}	94	E119^{cd}	92^{aa}	61	27*
5	58*	56	60^{a}*	74	124^{ab}	104^{d}	130	90^{a}	136	90*	58^{a}	18*
6	E 90^{cd}	M 82^{c}	52*	70^{ad}	115	124	122	112^{d}	136^{d}*	82^{d}*	62	M17^{c}*
7	68	76	52^{a}*	E 63^{cd}	133^{add}*	127	151	M106^{bc}	114	91^{a}*	66^{a}	23^{a}
8	78*	85^{a}	44^{d}	86*	105^{d}*	113^{d}	167^{ab}	E141^{cdd}	E145^{ac}	91^{d}*	E 37^{c}	47^{d}
9	M 55^{cd}	64	M 61^{c}*	89^{dd}	103*	116^{ad}	130^{ad}	157	159^{abd}	77	E 40^{c}	45^{a}
10	EE134^{ccd}	E 44^{acd}	47^{d}	W 98^{c}	EM128^{cc}	104^{a}	143	151^{d}	168^{b}	67	M 46^{c}	52^{d}*
11	118^{aa}	49^{d}	49	102^{a}	101	E119^{c}	131^{d}	157^{aa}	E136^{c}	56	E 66^{ac}*	49*
12	111	73	55	100^{a}	EE142^{cc}*	102*	118	M170^{ac}	150^{a}*	E 74^{ac}*	82	E56^{c}*
13	103	86*	E 55^{c}	EW112^{cc}	M121^{aac}	107^{d}*	101	159^{ad}	127	85^{a}*	84*	48^{a}*
14	84^{a}	76	46^{a}*	E126^{aac}	148^{aad}*	112^{a}*	97^{d}	138^{a}	92	E 68^{ac}	E 99^{ac}*	62*
15	86^{aad}	56	58	121^{b}	139	101^{a}	M 87^{c}	M146^{acd}	96^{a}*	E 73^{c}	87^{a}	58*
16	55	M 62^{ac}	W 55^{ac}	141^{d}	118	97	74*	122	83^{ad}*	68	111^{d}	53^{a}
17	71	M 62^{ac}	W 83^{ac}	109	93^{d}	92*	85^{ab}	128	69^{d}*	79^{a}	94*	52^{ad}
18	63	61	E112^{c}	102	79^{d}	MW 91^{cc}	86	111	67	E 74^{acd}	103^{b}	61*
19	E 70^{c}	EE 62^{cc}	133	94^{ad}	79	89	95^{a}	110^{a}	88	92^{d}	M 75^{c}	44^{d}
20	M 74^{c}	EM 82^{cc}	112	M125^{acdd}	68*	56^{aa}*	E113^{bc}	104^{d}	70	95	50	46*
21	E 86^{acd}	92^{dd}	E 89^{c}	125	EW 87^{cc}*	68	106	94^{b}	89^{ad}	86^{a}*	67^{d}	46^{d}
22	83	96^{d}	77	115^{a}	85*	68	96*	86	88	94^{d}	66^{a}*	47
23	77	98	74^{a}	M152^{acd}	93^{a}*	65^{dd}	80^{a}	72^{d}	88^{a}	94*	62	35*
24	W 90^{acd}*	93^{a}	66^{a}	151	E106^{ac}	74	67	75	107^{d}	112^{a}	E 61^{c}	41*
25	102^{aad}	112	48	134^{a}	107*	61	62	58^{a}	106	112^{bd}*	58	32^{a}*
26	M 86^{ac}	74^{a}	49	134^{abd}	97	84^{d}	53	69^{d}	98^{d}	100^{d}	M 59^{c}*	37^{a}
27	102*	101	41*	146*	104^{d}	E109^{c}	50^{a}	E 86^{c}	E105^{bcd}	80*	62^{a}	32*
28	103	92	35	145^{ad}*	138^{ad}	137^{d}	W 57^{cd}	85	131^{d}	64^{a}	61	31*
29	72^{a}		41	136*	172^{add}	134^{aa}	M 71^{c}	69	131^{a}	E 81^{c}	43^{a}	28*
30	76*		36	140	157	118^{a}	68	M 76^{c}	M137^{c}	85	43	47^{d}
31	76^{a}*		35		146		46	95^{b}*		74^{a}*		34
Mean	80.3	77.4	64.6	109.1	118.3	101.0	97.6	105.8	112.6	88.1	68.1	42.1

a = Passage of an average-sized group through the central meridian.
b = Passage of a large group or spot through the central meridian.
c = New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disk; *W*, on the western part; *M*, in the central-circle zone.
d = Entrance of a large or average-sized center of activity on the east limb.

supplemented by series furnished by other cooperating observatories for days (indicated by asterisks) on which no observations were possible at Zürich.

Table 2 gives the yearly means of the relative numbers, R, since the last minimum 1933 and the number of days without spots.

TABLE 2—*Yearly means of relative sunspot-numbers, R*

Year	R	Increase	No. spotless days
1933	5.7	-	240
1934	8.7	3.0	154
1935	36.1	27.4	20
1936	79.7	43.6	0
1937	114.4	34.7	0
1938	109.6	−4.8	0
1939	88.8	−20.8	0

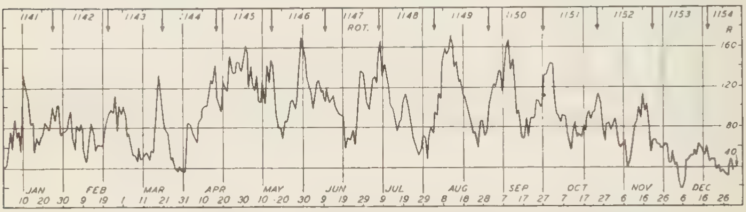


FIG. 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1939

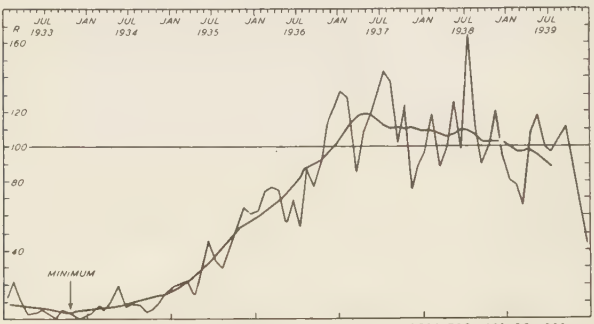


FIG 2—OBSERVED AND SMOOTHED MONTHLY RELATIVE NUMBERS FOR 1933 TO 1939

Figure 1 gives a graphical representation of the daily relative sunspot-numbers for 1939, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of the Figure. The secondary maxima and minima succeeding the rotation-periods do not represent real fluctuations in sunspot-activity, but are rather to be attributed to the influence of solar rotation, to a certain stability of the centers of activity for spots, and to the special distribution of these centers of activity in the direction of rotation.

Figure 2 shows the observed and smoothed monthly relative numbers for 1933 to 1939. The purpose of smoothing is to eliminate the secondary variations. The method of smoothing is as follows: For obtaining the mean of the epoch July 1, the average of the monthly means of the twelve months January to December is taken (m_1), and for the epoch August 1, the average of the monthly means for February to January (m_2). The mean of these $m=(m_1+m_2)$ 2, which represents the smoothed relative number for the middle of July, is used for the construction of the curve.

To this summary of spot-activity for the past year I am adding Table 3 showing the activity of the prominences by monthly means of the measured areas for the period 1931 to 1939.

The yearly means (Table 3, line *a*) have been obtained by averaging the 12 monthly means. The yearly means (line *b*) give the sums of the areas divided by the number of observations for each year. In the line *c* are the homogenized yearly means. It has been found that inhomogeneities have arisen in our series by including the observations at our station at Arosa after 1930 and again owing to a change of instrument (observation at the spectrohelioscope) after 1938. [For the method of homogenization see Astr. Mitt. Eidgen. Sternwarte, No. 139, p. 504.]

TABLE 3—*Monthly means of prominence-areas of 1931-1939*[1]

Month	1931[2]	1932	1933	1934	1935	1936	1937	1938[3]	1939[3]
I	193_{9}	518_{23}	404_{17}	480_{15}	751_{14}	1005_{6}	1672_{10}	1216_{9}	768_{13}
II	279_{9}	513_{30}	426_{15}	427_{35}	573_{11}	987_{15}	1699_{5}	1827_{18}	668_{22}
III	197_{20}	511_{23}	396_{34}	387_{20}	715_{27}	868_{23}	1027_{11}	859_{26}	634_{17}
IV	255_{15}	445_{18}	323_{18}	431_{31}	897_{7}	1071_{5}	1174_{16}	721_{23}	458_{20}
V	362_{21}	338_{17}	329_{16}	539_{34}	896_{19}	1284_{19}	1329_{25}	884_{20}	395_{11}
VI	294_{26}	443_{23}	565_{18}	592_{36}	738_{26}	905_{18}	1312_{13}	872_{25}	442_{22}
VII	468_{26}	437_{23}	568_{39}	616_{32}	885_{25}	790_{20}	1010_{15}	828_{24}	567_{27}
VIII	656_{22}	376_{34}	460_{32}	493_{19}	1206_{22}	965_{35}	896_{13}	616_{23}	529_{22}
IX	552_{22}	440_{21}	597_{17}	763_{30}	1399_{26}	1094_{17}	1312_{18}	471_{27}	549_{17}
X	655_{32}	302_{18}	582_{23}	625_{27}	1058_{8}	1314_{21}	1169_{16}	593_{21}	439_{8}
XI	480_{19}	363_{27}	319_{12}	542_{19}	1155_{14}	1505_{15}	842_{13}	466_{17}	608_{12}
XII	494_{25}	439_{17}	376_{24}	438_{17}	1505_{9}	1531_{14}	1004_{7}	819_{11}	782_{6}
Yearly	*a* 407	427	445	528	981	1110	1204	848	570
means	*b* 442_{245}	430_{274}	457_{265}	537_{305}	971_{208}	1096_{208}	1182_{172}	813_{244}	564_{197}
	c 406	353	384	462	816	979	1085	1097	761

[1]For corresponding returns for the years 1909-30, see Terr. Mag., **42**, 393, 1937.

[2]Zürich and Arosa from August 1931.

[3]Zürich, observation at the spectroscope and spectrohelioscope; from August 9, 1938, spectrohelioscope only.

EIDGEN. STERNWARTE,
Zürich, Switzerland

REVIEWS AND ABSTRACTS

CANADIAN POLAR YEAR EXPEDITIONS, 1932-33: *Terrestrial magnetism, earth-currents, aurora borealis (Volume 2); Chesterfield Inlet, Meanook, Saskatoon.* Ottawa, J. O. Patenaude, 185 pp. (1939).

This comprehensive report, issued by the Division of Meterological Services of Canada, gives in detail the results of the magnetic, earth-current, and auroral observations made at the three Canadian Polar-Year stations; the meteorological results and general descriptions of the stations and expeditions were presented in Volume 1.

The first section, by F. T. Davies, deals with the magnetic observations at Chesterfield Inlet, including field-measurements at Baker Lake and Dead Man Island. It begins with a brief description of the magnetic equipment and procedure at Chesterfield (latitude 63° 20′.2 north, longitude 90° 42′.3 west). Both high- and low-sensitivity la Cour variometers were used to record H, D, and Z. A quick-run magnetograph was also installed but inadequate power-supply resulted in little satisfactory record from it. Scale-values were determined by means of a Helmholtz coil. The approximate scale-values for the high-sensitivity variometer were, 1′ for D, 5.7γ for H, and 9.7γ for Z. For the low-sensitivity instruments the corresponding scale-values were 5′ for D, 20γ for H, and 14γ for Z, during most of the period of operation. For absolute observations, CIW magnetometer No. 15, a Smith portable magnetometer, and an earth-inductor were available—the first named was used most successfully at this station. Recording began on September 13, 1932, and continued through September 9, 1933, with very little loss of record.

The results of the observations are given in 108 tables, excellently arranged for convenient use in geomagnetic studies. In addition to mean hourly values of H, D, and Z, and the values and times of their daily maxima and minima, they include, mean diurnal-variation data for all days and for calm and disturbed days, ranges of diurnal variation, average departures of the mean hourly values from mean of day, extreme hourly ranges, extreme monthly values, and mean monthly, seasonal, and annual values for each of the elements recorded. The last group is also tabulated for X, Y, and I.

The mean value of H was found to be 3834γ. Its maximum value, 4189γ, was recorded on May 4, 1933, and the minimum value of 2907γ occurred on November 16, 1932, giving a total range in H of 1282γ or about one-third of the mean value for the year. The mean value of Z was 60752γ with a maximum of 61577γ on November 16, and a minimum of 60091γ on March 24. The mean value of D was 12° 36′.4 west and the declination ranged from 28° 15′ west on July 24 to 5° 07′ west on August 6. Particular attention is called to the large changes in the angular value of D as shown in the tables of the extreme hourly ranges in this element.

Supplementing the work done at Chesterfield, field-measurements were made at Baker Lake, 175 miles west-northwest, and at Dead Man Island, 45 miles south of Chesterfield, during the month of August, 1933. The results of these measurements are shown in comparison with the records obtained simultaneously at Chesterfield, and are combined, in the case of Dead Man Island, with those obtained at that station in 1884 and 1912 to provide an estimate of the secular changes which have occurred in that interval.

The second section describes the magnetic work and records obtained at Meanook (latitude 54° 37′ north, longitude 113° 20′ west) by W. E. W. Jackson and E. H. Vestine. Twelve variometers were in operation at this station during the Polar Year, three of which were the regular station variometers and the remaining nine were la Cour instruments, standard, low-sensitivity, and quick-running, respectively. For the standard la Cour variometers the scale-values, here again determined by use of the Helmholtz coil, were approximately 1′ for D, 8γ for H, and 10.7γ for Z. The absolute instruments consisted of a Kew-type magnetometer and an earth-inductor.

The results of the observations, which cover the period from August, 1932, to September, 1933, with practically no loss of record, are given in 69 tables, following the same arrangement and giving the same data as those presented for Chesterfield except that no tables showing the extreme hourly ranges in the three elements are included. The diurnal-variation data are corrected for non-cyclic change as were the corresponding

records at Chesterfield. The mean values recorded at Meanook are as follows: 26° 23'.3 east for D, 12736γ for H, and 59442γ for Z.

The third section, by B. W. Currie, reports in detail on the earth-current measurements made at Chesterfield Inlet from October, 1932, to September, 1933. High-sensitivity galvanometers, shunted by their critical-damping resistances, were used in series with large resistances to determine the earth-potentials, the deflections being recorded photographically by a la Cour recorder. The equipment was the same as that used at College-Fairbanks and in its essential features was like that at the permanent station at Tucson. The use of large-series resistances minimizes the effects of variations in the contact-resistances at the electrodes and facilitates calibration of the apparatus.

Satisfactory electrode-sites are scarce at Chesterfield since most of the ground-surface consists of bare rock. Practically the only possible locations are sand-pockets remaining from prehistoric periods of submergence. In four such pockets, electrodes consisting of cross-shaped grids of pure lead wire were installed at depths of from two to three feet. The distance between the south and north electrodes was 1.31 km and that between the west and east electrodes was 0.86 km. The sites were chosen so that the lines crossed approximately at their centers and hence the performance of the individual electrodes could be checked by using them in different combinations. The contact-resistance of the electrodes was about 2000 ohms initially, increased markedly during the winter, reaching a value of 10^6 ohms in one case, and dropped to a few thousand ohms in the summer. The series-resistance used was 2.5 megohms. The effect of contact-resistance on the recorded values was consequently quite appreciable during the winter but was never great enough to impair their value seriously as far as the general features of the current-flow are concerned.

The most striking characteristic of the records is the high ratio in the magnitude of the short-period fluctuations during disturbances and that of the more regular variations on calm days. This has been observed at all high-latitude stations and, because of it no single sènsitivity is completely satisfactory. The sensitivity adopted was high enough to give a satisfactory record of the diurnal variation so that the general features of the currents could be determined even though some record was lost during disturbances.

Insulated wires laid on the surface of the ground connected the electrodes to the recorder. During the winter, whenever the wind-velocity exceeded 20 miles per hour, the traces showed very rapid oscillations of large amplitude which completely obscured the normal earth-current record. The appearance of the record suggested mechanical vibration of the galvanometers but this explanation is ruled out by the fact that the zero- and hcur-marks were unaffected. Currie attributes the deflections to frictional charges developed by flying snow-particles, either on the lines or on the ground near the electrodes. This is supported by the fact that this "snow-drift" effect was not in evidence until the resistances of the electrodes became so large as to be comparable to those of the galvanometer circuits. Attempts to prevent this effect by covering the lines with snow improved the records temporarily but the drift-storms soon removed the cover.

Despite the loss of record due to the combination of high electrode-resistances, the "snow-drift" effect, and the frequency of short-period fluctuations, complete and scalable traces were obtained on 81 days well distributed throughout the year. The results, already summarized in a previous paper by Currie[1], show that the diurnal variation in earth-current flow at Chesterfield is very similar to that found at College-Fairbanks. The results are particularly interesting in that they confirm the indications from the College-Fairbanks records that the eastward component at high latitudes undergoes a great seasonal change, the diurnal-variation curve developing from a small double-period curve in the winter to a single-period curve of large amplitude in the summer. The possibility that this unusual feature of the records arose from errors of measurement is quite definitely eliminated by the fact that it is found at both stations. In addition to the mean hourly values for the 81 undisturbed days, the report gives in 20 tables the extreme hourly ranges for each component in convenient form for studies involving disturbances and their correlation with auroras and magnetic disturbances. A discussion of the earth-current disturbances, of their diurnal variation, and of their relationship to the auroral and magnetic records completes the section.

Section 4, by T. Alty and F. J. Wilson, deals with the measurements of the height of the aurora at Saskatoon (latitude 52° 07' 53" north, longitude 106° 37' 47" west) during the winter of 1932-33. The cameras used were of the type designed by Vegard and Krogness, providing for six photographs on each plate. The lenses were Kino Plasmat, of focal length five cm and aperture f.1.5. The principal station was located at the

[1]Terr. Mag., **40**, 317-324 (1935).

University of Saskatchewan, and the secondary station at St. Peter's College, Muenster, 112 km distant. Detailed results of the measurements of 56 auroras are given numerically in tables and graphically in diagrams. They indicate that the most usual height of the lower limit of auroral arcs and bands at this station is about 105 km—in close agreement with the results obtained by Norwegian observers. The lowest height measured was about 60 km, a lower value than has been reported from any other station. Long auroral streamers were found to extend from some 300 km at their upper extremities to about 70 km at their lower edges. Eighteen excellent prints of typical auroral photographs are appended.

The fifth and final section, also by B. W. Currie, describes the auroral observations at Chesterfield Inlet, which included both visual observations and photographic measurements. The cameras were similar to those used at Saskatoon, the main station being at Chesterfield and the secondary station being south of Chesterfield on the shore of Hudson Bay. The length of the base line was 32.14 km. The mean value of the lower limit for all forms was found to be 115.6 km and the lowest value recorded was 72 km. Two interesting features of the results were the high mean value for quiet forms in February and high values for forms with ray-structure during March. The upper limit of forms with ray-structure varied widely with values from 300 to 400 km not uncommon. The diurnal variation, both as to predominating form and intensity, was determined from visual observation on 51 clear nights. The maximum is found to occur practically at magnetic midnight. Quiet arcs and bands predominated in the early evening, while forms with ray-structure were most frequent at 07^h local time. Detailed results from 200 parallactic photographs are given in tables and diagrams.

The authors are to be congratulated on the completeness and clarity of this report and on the excellence of the arrangement of the data presented—all of which make it a valuable contribution to the study of geophysics.

W. J. Rooney

LETTERS TO EDITOR

(See also pages 338 and 344)

WIDE-RANGE MAGNETOGRAPH AT ABINGER OBSERVATORY

A wide-range magnetograph has recently been set up at Abinger to record variations of declination and horizontal intensity on a scale corresponding to 20 gammas per millimeter in each element. The magnetograph has been in regular operation since the beginning of June 1940, and has already proved its worth by showing plainly, on June 25, a large and extremely rapid movement of the *H*-trace which possibly would have escaped notice on the trace of the ordinary la Cour magnetograph.

As a temporary measure we are using for horizontal intensity the variometer which was superseded when the la Cour magnetograph was installed two years ago. The variometer has been desensitized to one-seventh by placing beneath it eight strongly magnetized needles oriented at right-angles to the magnetic meridian. It can thus be restored at any moment to its former use if occasion arises. I consider that the ranges in vertical intensity which are likely to occur at Abinger can be dealt with completely by the ordinary la Cour arrangement of auxiliary rays.

ROYAL OBSERVATORY GREENWICH, *London, S. E. 10, July 17, 1940* H. SPENCER JONES

WIDE-RANGE MAGNETOGRAPH AT CHELTENHAM MAGNETIC OBSERVATORY

On June 18, 1940, installation of insensitive declination (D) and horizontal-intensity (H) variometers was completed at the Cheltenham Magnetic Observatory. Briefly, the la Cour H-variometer uses a magnet whose moment is between 3.5 and 4.0 units with a la Cour type quartz-fiber suspension of such size that the scale-value is about 30 gammas per mm at a recording distance of 128 cm. The la Cour D-variometer uses a magnet whose moment is between 0.8 and 0.9 unit with a quartz fiber of a size to give a scale-value of about 4'.6 per mm (24 gammas per mm) at a recording distance of 175 cm. The recorder uses paper 19.8 by 53 cm in size, and has a time-scale of 20 mm per hour. Both normal traces are located fairly near the center of the magnetogram to allow a wide range of variation without loss of record.

It may be mentioned that the la Cour type quartz-fiber suspensions used in the insensitive variometers were recently made by the writer in Washington, using the technique demonstrated by Dr. la Cour during his visit to the United States last year.

Since there was insufficient room on the available pier no attempt was made to include a vertical-intensity (Z) variometer in the magnetograph. For some years, however, the Adie Z-variometer at Cheltenham has been operating at a scale-value of about 12 gammas per mm without loss of record during storms, and it is felt that this fulfills the requirement for an insensitive Z-trace.

The regular magnetograph at Cheltenham operates at 1' per mm (5.25 gammas per mm) for D, 2.66 gammas per mm for H, and 3.95 gammas per mm for the Z.

The writer has been informed that it will be the custom to use the insensitive magnetograms for ranges in the values of the elements during periods when the K-number exceeds 6.

U. S. Coast and Geodetic Survey, J. H. Nelson
Washington, D. C., July 22, 1940

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS AT WASHINGTON, D. C., APRIL TO JUNE, 1940[1]

The following ionosphere data are in continuation of those published in this Journal[2] and in each issue subsequently.

Table 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.* (Average for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^{\circ}_{F_1}$	$f^{\circ}_{F_2}$
h	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*
				April, 1940		
00			322			4910
01			317			4730
02			312			4370
03			304			4030
04			312			3740
05	118#		310			3610
06	123#		260	1960		4780
07	127#		234	2560	3930	5950
08	120	218	316	2980	4390	6450
09	116	211	332	3300	4530#	6950
10	113	205	356	3520	4640#	7250
11	113	206	355	3650	4710#	7470
12	114	206	362	3710	4780#	7730
13	113	212	340	3660	4750#	7820
14	114	220	351	3560	4650#	7950
15	115	224	352	3400	4550#	8070
16	120	231	303	3100	4270	8030
17	130#	238	287	2690	3840	8020
18			259	1850	3100	7920
19			253	1380*		7630
20			250			6950
21			274			6150
22			289			5610
23			322			5170

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^{\circ}_{F_1}$	$f^{\circ}_{F_2}$
h	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/s*
				May, 1940		
00			310			514
01			311			48
02			308			46
03			303			41
04			301			37
05	121#		285	1660*		40
06	120#		245	2270	3810*	49
07	123#	234	326	2730	4030	57
08	125#	220	345	3130	3660	60
09	121#	217	349	3420	4570*	634
10	121#	211	369	3630	4620#	65
11	119#	212	380	3730	4800#	66
12	116#	214	360	3780	4760#	69
13	116#	221	354	3730	4820#	710
14	118#	222	354	3650	4760#	71
15	115#	222	357	3490	4640#	714
16	120#	228	344	3220	4570*	71
17	120#	235	310	2840	4080	73
18		253	281	2350	3500	74
19			253	1580*		74
20			245			71
21			263			63
22			283			58
23			297			54

The data given here are in part somewhat different from those presented graphically each month in *Proceedings of the Institute of Radio Engineers*, because those are for undisturbed days while these are for all days of the month.

These data also give implicitly the maximum ionization-densities of the ionosphere layers. The equivalent electron-density in electrons per cubic centimeter is 0.0124 times the square of the critical frequency.

Key to symbols:

EST = Eastern Standard Time (75° west meridian time).

[1]Communicated by the Director of the National Bureau of Standards of the United States Department of Commerce.

[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*—Continued

(Averages for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$
h	*km*	*km*	*km*	*kc/sec*	*kc/sec*	*kc/sec*
				June 1940		
00			300			5490
01			298			5290
02			299			4730
03			297			4240
04			319	1330#		3750
05			286	1810		4060
06		236	327	2490	3730	4950
07	122	227	399	2950	4290	5520
08	126	229	371	3300	4510	5730
09	122#	217	400	3570	4650	5960
10	122#	216	368	3800	4820	6340
11	120#	213	413	3860	4840	6290
12	120#	214	416	3880	4910	6460
13	120#	214	394	3870	4900	6360
14	122#	213	414	3770	4860	6550
15	120#	222	370	3610	4750	6690
16	123	232	355	3380	4590	6930
17	123	230	330	3070	4360	7190
18		238	294	2610	3850	7340
19			265	2040		7340
20			266	1130		7310
21			276			6960
22			283			6310
23			293			5940

= manual measurements made on Wednesdays; other data were usually obtained daily.

* = less than ten measurements.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, APRIL TO JUNE, 1940

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The three columns for each month in Table 1 give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 409-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937); **43**, 83-87, 174-178, 328-331, 491-494 (1938); **44**, 94-99, 215-219, 349-352, 487-491 (1939); **45**, 99-104, 214-218 (1940).

Beginning with October 27, 1938, Mount Wilson discontinued supplying sunspot-numbers, since interested investigators have available the sunspot-counts from Tokyo published regularly in the weekly Science Service Research Aid Announcements and the monthly tabulation of Wolf numbers, promptly prepared at Zürich, which appear monthly in the Monthly Weather Review and quarterly in this Journal.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937, the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west

Table 1—*Summary American URSI daily broadcasts of cosmic data, April to June, 1940*

Greenwich date	April Magnetism Character	Type	GMT beginning disturbance h	m	May Magnetism Character	Type	GMT beginning disturbance h	m	June Magnetism Character	Type	GMT beginning disturbance h	m
1	1	*i*	..	..	0	...	..	..	0	...	..	..
2	2	*i*	16	05	0	...	..	..	0	...	..	..
3	2	*i*	..	..	0	...	..	..	0	...	..	..
4	1	*p*	..	..	0	...	..	..	0	...	..	..
5	0	...	..	..	0	...	..	..	1	*i*	20	50
6	0	...	..	..	0	...	..	..	1	*i*	..	..
7	0	...	..	..	0	...	..	..	1	*i*	..	..
8	0	...	..	..	0	...	..	..	1	*i*	..	..
9	0	...	..	..	0	...	..	..	1	*o*	..	..
10	0	...	..	..	0	...	..	..	0	...	..	..
11	0	...	..	..	0	...	..	..	0	...	..	..
12	0	...	..	..	0	...	..	..	0	...	..	..
13	0	...	..	..	0	...	..	..	0	...	..	..
14	0	...	..	..	0	...	..	..	1	*i*	08	01
15	1	*i*	..	..	0	...	..	..	1	*i*	..	..
16	1	*i*	..	..	0	...	..	..	1	*i*	..	..
17	0	...	..	..	0	...	..	..	0	...	..	..
18	0	...	..	..	1	*i*	00	00	1	*i*	..	..
19	0	...	..	..	0	...	..	..	0	...	..	..
20	1	*i*	03	30	0	...	..	..	0	...	..	..
21	1	*i*	..	..	0	...	..	..	0	...	..	..
22	0	...	..	..	1	*i*	01	00	1	*i*	10	50
23	0	...	..	..	1	*i*	17	54	1	*i*	..	..
24	0	...	..	..	1	*i*	..	..	0	...	..	..
25	1	*i*	02	05	1	*i*	..	..	2	*i*	02	54
26	1	*i*	..	..	1	*i*	01	22	1	*i*	17	18
27	0	...	..	..	1	*i*	..	..	1	*i*	..	..
28	0	...	..	..	1	*i*	..	..	0	...	..	..
29	0	...	..	..	0	...	..	..	0	...	..	..
30	1	*i*	..	..	0	...	..	..	1	*i*	..	..
31					0	...	..	..				
Mean	0.4	...	..	..	0.3	...	..	..	0.5	..	..	..

Greenwich mean time for ending of storms: 24^h, April 3; 13^h, April 21; 14^h, April 26; 19^h, May 18; 12^h, May 22; 04^h, May 25; 07^h, May 27; 06^h, June 8; 03^h, June 16; 02^h, June 23; 10^h, June 26; 04^h, June 27

TABLE 2—*Kennelly-Heaviside Layer heights, Washington, D. C., April to June, 1940*
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1940	*kc sec*	*km*	*1940*	*kc sec*	*km*	*1940*	*kc sec*	*km*	*1940*	*kc sec*	*km*
pr. 3	2,800	120	Apr. 24	5,400	330	May 15	4,400	230	Jun. 5	5,400	400
" "	3,300	120	" "	5,600	320	" "	4,600	290	" "	5,600	380
" "	3,450	130	" "	5,800	320	" "	4,800	340	" "	6,000	140
" "	3,500	270	" "	6,200	300	" "	5,000	250	" "	6,000	380
" "	3,550	240	" "	7,000	320	" "	5,400	280	" "	6,400	410
" "	3,600	230	" "	7,800	340	" "	5,800	400	" "	6,600	430
" "	3,800	210	" "	8,200	360	" "	6,200	420	" "	7,000	430
" "	3,900	220	" "	8,200	480	" "	6,200	500	" "	7,000	530
" "	4,000	250	" "	8,400	370	" "	6,400	430	" "	7,200	440
" "	4,600	460	" "	8,400	510	" "	6,400	620	" "	7,200	650
" "	4,800	510	" "	8,800	410	" "	7,000	480	" "	7,600	460
" "	5,000	450	" "	9,000	450	" "	7,200	680	" "	8,000	660
" "	5,200	430	" "	9,200	490	" "	7,400	*	" "	8,200	*
" "	5,600	520	" "	9,300	*	" 22	2,500	110	" 12	2,500	110
" "	5,800	500	May 1	2,500	110	" "	3,000	110	" "	4,000	120
" "	5,800	770	" "	3,000	110	" "	3,700	110	" "	5,000	120
" "	6,000	490	" "	3,500	110	" "	3,800	250	" "	6,000	120
" "	6,200	570	" "	3,800	120	" "	3,900	210	" "	6,400	120
" "	6,400	*	" "	3,800	230	" "	4,200	210	" "	6,400	400
" 10	2,500	110	" "	4,100	100	" "	4,400	250	" "	6,800	430
" "	3,900	120	" "	4,200	120	" "	4,600	350	" "	7,000	490
" "	4,000	200	" "	4,200	220	" "	4,700	430	" "	7,400	450
" "	4,100	190	" "	4,600	290	" "	4,800	650	" "	7,800	480
" "	4,200	220	" "	5,000	440	" "	4,900	610	" "	8,000	120
" "	4,400	250	" "	5,200	370	" "	5,000	550	" "	8,000	550
" "	4,800	280	" "	5,600	330	" "	5,200	490	" "	8,400	130
" "	5,000	300	" "	6,200	330	" "	5,400	510	" "	9,000	160
" "	5,400	300	" "	7,000	370	" "	5,500	570	" 19	3,700	150
" "	6,200	300	" "	7,000	430	" "	5,700	570	" "	3,750	250
" "	7,800	310	" "	7,400	390	" "	5,700	690	" "	3,800	230
" "	8,600	310	" "	7,400	560	" "	6,000	520	" "	4,000	250
" "	9,000	330	" "	7,800	420	" "	6,300	570	" "	4,200	250
" "	9,000	400	" "	8,200	550	" "	6,500	650	" "	4,400	250
" "	9,400	340	" "	8,400	*	" "	6,600	700	" "	4,600	290
" "	9,400	420	" 8	2,500	120	" "	6,700	*	" "	4,800	430
" "	9,800	370	" "	3,500	120	" 29	2,500	130	" "	5,000	550
" "	9,800	500	" "	3,700	120	" "	3,000	130	" "	5,200	410
" "	10,200	410	" "	3,750	210	" "	3,600	120	" "	5,400	350
" "	10,600	490	" "	3,800	240	" "	3,800	130	" "	5,800	350
" "	10,800	*	" "	3,850	220	" "	4,000	120	" "	6,000	370
" 17	2,500	110	" "	4,050	220	" "	4,000	260	" "	6,000	470
" "	2,900	130	" "	4,200	220	" "	4,200	250	" "	6,400	390
" "	3,900	170	" "	4,400	260	" "	4,400	290	" "	6,400	550
" "	3,950	210	" "	4,600	330	" "	4,800	560	" "	6,800	420
" "	4,000	200	" "	4,800	360	" "	5,000	470	" "	7,000	460
" "	4,200	240	" "	5,000	350	" "	5,400	380	" "	7,200	590
" "	4,500	270	" "	5,400	330	" "	5,800	120	" "	7,400	*
" "	5,000	370	" "	6,200	360	" "	5,800	370	" 26	2,500	120
" "	5,200	400	" "	7,000	380	" "	6,000	420	" "	3,500	140
" "	5,400	370	" "	7,400	400	" "	6,200	450	" "	3,900	260
" "	5,800	350	" "	7,400	440	" "	6,400	410	" "	4,100	230
" "	6,400	380	" "	7,800	400	" "	6,400	580	" "	4,500	260
" "	7,200	440	" "	7,800	540	" "	6,800	110	" "	4,800	350
" "	7,600	490	" "	8,200	420	" "	6,800	430	" "	4,900	700
" "	8,800	670	" "	8,600	500	" "	7,000	470	" "	5,000	500
" "	9,000	*	" "	8,800	*	" "	7,200	660	" "	5,300	450
" 24	3,500	130	" 15	2,500	110	" "	7,400	*	" "	5,600	340
" "	3,700	170	" "	3,000	110	Jun. 5	3,000	130	" "	5,600	550
" "	3,800	250	" "	3,300	120	" "	3,700	130	" "	5,700	*
" "	4,000	230	" "	3,700	120	" "	4,600	120	" "	6,000	490
" "	4,400	240	" "	3,750	220	" "	4,600	230	" "	6,300	550
" "	4,800	290	" "	3,800	200	" "	4,800	320	" "	6,400	650
" "	5,000	310	" "	3,900	190	" "	5,000	490	" "	6,500	*
" "	5,200	330	" "	4,200	220	" "	5,200	450			

* =No value obtained.

meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March, 6, 1937, solar-constant values were discontinued owing to an important change in methods.

The data for Table 2 of Kennelly-Heaviside Layer heights which are self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department

TABLE 3—*American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for April to June, 1940*

Day	April			May			June		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	1.5	0.9	1.2	0.1	0.3	0.2	0.0	0.0	0.0
2	0.4	1.1	0.7	0.1	0.0	0.0	0.2	0.2	0.2
3	1.6	1.2	1.4	0.1	0.1	0.1	0.0	0.1	0.1
4	0.6	0.5	0.5	0.1	0.0	0.0	0.0	0.0	0.0
5	0.4	0.0	0.2	0.3	0.0	0.1	0.1	0.6	0.4
6	0.4	0.1	0.2	0.0	0.0	0.0	1.1	0.6	0.9
7	0.0	0.0	0.0	0.5	0.1	0.3	0.9	0.6	0.7
8	0.0	0.0	0.0	0.2	0.1	0.1	0.6	0.6	0.6
9	0.0	0.0	0.0	0.4	0.4	0.4	0.5	0.4	0.5
10	0.0	0.0	0.0	0.4	0.6	0.5	0.1	0.0	0.1
11	0.0	0.4	0.2	0.6	0.4	0.5	0.0	0.0	0.0
12	0.2	0.0	0.1	0.6	0.4	0.5	0.0	0.2	0.1
13	0.3	0.4	0.3	0.2	0.3	0.2	0.0	0.0	0.0
14	0.5	0.2	0.4	0.5	0.4	0.4	0.5	1.1	0.8
15	0.3	0.6	0.4	0.4	0.5	0.5	1.0	0.6	0.8
16	0.6	0.2	0.4	0.0	0.1	0.0	0.5	0.5	0.5
17	0.3	0.0	0.2	0.3	0.1	0.2	0.5	0.4	0.4
18	0.0	0.0	0.0	1.1	0.8	0.9	0.9	0.4	0.6
19	0.1	0.1	0.1	0.3	0.1	0.2	0.5	0.3	0.4
20	0.4	0.7	0.6	0.1	0.4	0.2	0.1	0.0	0.0
21	0.8	0.5	0.6	0.3	0.2	0.2	0.0	0.0	0.0
22	0.6	0.2	0.4	1.1	0.4	0.8	0.2	0.5	0.4
23	0.0	0.0	0.0	0.3	0.8	0.5	0.1	0.1	0.1
24	0.0	0.0	0.0	1.4	1.1	1.2	0.6	0.5	0.5
25	1.4	1.4	1.4	0.5	0.3	0.4	1.3	1.8	1.5
26	1.1	0.4	0.8	0.9	0.8	0.9	0.8	0.6	0.7
27	0.2	0.2	0.2	0.5	0.5	0.5	0.2	0.1	0.1
28	0.2	0.4	0.3	0.6	0.4	0.5	0.0	0.1	0.0
29	0.4	0.1	0.2	0.3	0.2	0.2	0.0	0.4	0.2
30	0.3	0.6	0.4	0.0	0.0	0.0	0.5	0.4	0.4
31				0.0	0.0	0.0			
Means	0.4	0.3	0.4	0.4	0.3	0.3	0.4	0.4	0.4

of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_3, and its values for the first twelve, second twelve, and twenty-four hours of each Greenwich day for April to June 1940, are given in Table 3.

H. F. Johnston

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., July 12, 1940

SOLAR AND MAGNETIC DATA, APRIL TO JUNE, 1940, MOUNT WILSON OBSERVATORY

The magnetic storm of April 2-3 probably belonged to the series of disturbances which began with the great magnetic storm of March 23-28 and which was obviously associated with the active sunspot-group, Mount Wilson No. 6783. When the storm of April 2-3 began, however, Group 6783 was 98° west of the central meridian and therefore was not visible. At the beginning of the storm of April 25-26 this same group was at 40° west longitude, having crossed the central meridian for the second time. In May the group returned again and was 22° east of the central meridian at the beginning of the storm of May 18, and 54° west at the beginning of the storm of May 23-25. All the magnetic storms from March 23 to May 25 may therefore have been associated with the same group of sunspots.

Magnetic storms

Greenwich mean time							Range hor. int.
Beginning				Ending			
1940		*h*	*m*	*d*	*h*	*m*	–
Apr.	2	16	..	3	23	..	170
	25	2	04*	26	14	..	170
May	18	4	..	18	19	..	115
	23	17	53*	25	4	..	115
	26	1	18*	27	7	..	110
June	14	8	00*	15	11	..	130
	25	2	54*	26	10	..	155

*Sudden commencement.

When the storm of May 26-27 began, Groups 6843, 6845, and 6847 were 12° west, 8° east, and 44° east, respectively. No. 6845, although the smallest, was probably the most active of these groups.

The magnetic storm on June 14-15 was probably associated with the active group No. 6860, and the storm on June 25-26 with No. 6877.

On June 22, a sudden commencement occurred at $10^h\ 48^m$ GMT, but no storm followed.

Day	April 1940						May 1940						June 1940					
	K_2						K_2						K_2					
	Whole disk	Central zone	*Ha* bright	*Ha* dark	No. groups	Mag'c char.	Whole disk	Central zone	*Ha* bright	*Ha* dark	No. groups	Mag'c char.	Whole disk	Central zone	*Ha* bright	*Ha* dark	No. groups	Mag'c char.
1	..	..	..	..	..	1.5	2	3	2	4	4^b	0	3	2	2	3	7	0
2	3	2	2	4	9^f	0.5	2	3	2	4	4	0	3	3	3	4	9^b	0
3	..	..	3	4	10^b	2	3	3	2	5	3	0	3	3	3	4	7	0
4	..	..	..	..	7	0.5	3	3	3	5	4	0	3	2	3	4	8^a	0
5	3	3	3	4	..	0.5	3	2	3	5	2	0	3	2	3	4	7^h	0.5
6	3	4	3	4	5	0	3	2	3	4	3	0	3	3	3	3	9	1
7	3	3	3	3	7	0	2	2	3	3	2	0	3	3	4	3	10	1
8	3	2	2	2	9^b	0	2	2	3	3	4^b	0	3	3	4	2	10^b	0.5
9	3	1	3	2	6	0	3	3	3	3	5^b	0.5	3	2	4	3	10	0.5
10	3	2	3	2	7	0	2	3	3	3	4	0.5	3	3	4	2	11	0
11	3	3	3	2	6	0	2	3	3	3	4	0.5	3	3	4	3	11	0
12	3	3	3	3	4	0	3	3	3	2	6	0.5	3	3	4	2	$9^{a,f,g}$	0
13	2	2	3	3	4	0	2	3	3^c	2	6	0	4	4	4	3	8	0
14	2	2	2	3	7	0	3	3	3	2	7^e	0.5	3	4	4	3	8	1
15	..	..	..	..	..	0.5	3	2	3	3	7	0.5	3	3	3	3	8	0.5
16	3	3	3	2	5^f	0.5	3	2	3	3	7	0	3	2	3	3	8	0.5
17	3	2	3	2	7	0	3	2	4	4	7	0	3	3	3	4	8	0.5
18	3	1	..	..	7	0	3	3	3	3	6^g	1	2	2	2	3	8	1
19	3	2	3	2	7	0	3	3	3	3	7^h	0	2	1	2	3	5	0.5
20	3	3	..^{d}	..	9	0.5	3	3	4	2	7^b	0	2	1	2^d	2	5	0
21	3	3	3^c	3	10	0.5	3	3	3	2	5	0.5	2	2	2	2	5	0
22	3	4	3^c	3	8^h	0.5	3	2	3	2	7^b	1	2	2	2	3	5^g	0.5
23	..	..	..	..	..	0	3	2	3	2	9	0.5	3	3	3^c	3	6	0
24	..	..	..	..	..^{h}	0	..	..	..	..	8	1	3	3	3	2	11	0.5
25	..	..	..	..	..	1.5	..	..	..	..	7	0.5	3	3	4	3	$12^{b,h}$	2
26	..	..	..	..	..	1	..	..	..	..	4	1	3	3	4	3	10	0.5
27	..	..	..	..	..	0	..	..	..	..	4^f	0.5	3	3	4	3	9	0
28	2	1	2^d	3	4	0	..	..	..	..	5	0.5	3	4	4	2	9^f	0
29	2	2	2	4	3	0	3	3	3	4	6^f	0	..	..	..	..	8	0.5
30	3	3	3	5	3	0.5	3	3	4	3	6	0	3	3	4	3	7^h	0
31							3	3	3	4	4	0						
Mean	2.8	2.4	2.8	3.0	6.5	0.4	2.7	2.7	3.0	3.2	5.3	0.3	2.9	2.7	3.2	2.9	8.3	0.4

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

$^{a, b}$ Formation of a new group which later developed to average size or larger: (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY,
Pasadena, California

SETH B. NICHOLSON
ELIZABETH STERNBERG MULDERS

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

April to June, 1940

(*Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^h $01^m.3$ W. of Gr.*)

April 2-3—A small magnetic storm began gradually at about 17^h GMT, April 2, and slowly increased to maximum values at 04^h, April 3. During the major portion of the storm the traces moved with large regular periodic motion. After 10^h, April 3, the storm gradually decreased. Ranges: *D*, 166′; *H*, 769 gammas; *Z*, 610 gammas.

April 25-26—A small magnetic disturbance began abruptly at 02^h 04^m GMT, April 25. The horizontal intensity decreased 25 gammas and then increased 95 gammas during the first two minutes of the storm. Thereafter the storminess increased. After 05^h the magnetic conditions gradually subsided. The traces remained mildly disturbed until 18^h, April 26. Ranges: *D*, 63′; *H*, 860 gammas; *Z*, 620 gammas.

May 18—A moderate magnetic disturbance was recorded on May 18. It began gradually at about 05^h GMT, with bays of large amplitude. The disturbance ended suddenly at 13^h. Ranges: *D*, 78′; *H*, 655 gammas; *Z*, 575 gammas.

May 22—A small disturbance began abruptly at 03^h 54^m GMT, May 22, with a sudden increase of 240 gammas in *H* during the first five minutes, followed by a decrease of about the same amount during the next four minutes. Similar peaks occurred on the other components. The traces were moderately disturbed with large sweeping changes until about 11^h. The record was then normal. Ranges: *D*, 83′; *H*, 730 gammas; *Z*, 630 gammas.

May 23-25—A small magnetic storm began at 17^h 52^m GMT, May 23, with a sudden commencement on all traces. The storm gradually increased to maximum values at 09^h, May 24. After 15^h, May 24, the storm gradually subsided, and ended at 04^h, May 25. Ranges: *D*, 80′; *H*, 1770 gammas; *Z*, 1115 gammas.

June 6—A short disturbed period occurred from 03^h to 13^h GMT, June 6. There were several large bays during the interval. Ranges: *D*, 80′; *H*, 920 gammas; *Z*, 605 gammas.

June 25-26—A magnetic storm began abruptly at 02^h 52^m GMT, June 25. Unfortunately the magnetograph-recorder stopped at 10^h, June 25 and was not started until 17^h. The major portion of the storm was lost. After 17^h, June 25, the traces had begun a return to normal values. The storm ended at 10^h, June 26.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory

April to June, 1940

(*Latitude 38° 44'.0 N., longitude 76° 50'.5 or 5^h $07^m.4$ W. of Gr.*)

April 2-4—A mild storm began at 16^h 12^m GMT, April 2. Its greatest activity took place between 02^h and 08^h, April 3. It ended at 04^h, April 4. Ranges: *D*, 64'; *H*, 270 gammas; *Z*, 315 gammas.

April 25-26—A moderate storm began abruptly at 02^h 05^m GMT, April 25. The elements were active during the following three hours when the ranges were: *D*, 41'; *H*, 225 gammas; and *Z*, 125 gammas. The elements were then relatively quiet until 17^h 20^m, April 25, when the storm continued with moderate activity until midnight April 26. *Z* was high between 17^h, April 25, and 01^h, April 26.

May 23-25—A disturbance began abruptly at 17^h 52^m GMT, May 23, and continued until 04^h, May 25. Ranges: *D*, 29'; *H*, 200 gammas; *Z*, 160 gammas.

June 5-10—A mild disturbance began at 17^h GMT, June 5, and continued until June 10 at 09^h. Ranges: *D*, 25'; *H*, 153 gammas; *Z*, 125 gammas.

June 22-23—A sudden commencement occurred at 10^h 50^m GMT, June 22. The disturbance following it was slight and ended at 02^h, June 23.

June 24-26—A storm developed gradually beginning at 17^h GMT, June 24. At 02^h 55^m, June 25, a sudden shift in the traces of all the elements ushered in the main phase of the storm. The greatest activity took place between 09^h and 17^h, June 25. The storm ended at 10^h, June 26. Ranges: *D*, 98'; *H*, 500 gammas; *Z*, 230 gammas.

Albert K. Ludy, *Observer-in-Charge*

Tucson Magnetic Observatory

April to June, 1940

(*Latitude 32° 14'.8 N., longitude 110° 50'.1 or 7^h $23^m.3$ W. of Gr.*)

April 2-4—At 16^h GMT, April 2, minor activity started, with some increase in disturbance until 01^h 30^m, April 3, at which time there was a considerable increase, *H* having a range of 120 gammas and *D* a range of 15' within one hour. This long-period activity continued for seven hours and was followed by short-period activity of small amplitudes to 23^h, April 3. A slightly disturbed condition prevailed for about one day longer with no definite ending.

April 25-26—A moderate storm began at 02^h 05^m GMT, April 25, with an increase in *H* of 45 gammas in two minutes, followed by a decrease of 190 gammas to a minimum at 05^h 00^m and then a return to normal. During the same period *D* increased 25' and returned to normal at about the time of the minimum in *H*. The storm continued with moderate long-period changes and a lowered *H* to an indefinite ending at about 12^h, April 26.

May 23-25—A moderate storm began at 17^h 54^m GMT, May 23, with a sudden rise in *H* of 32 gammas, and with a small but sudden change in *D*. The storm was characterized by small short-period variations and a bay in *H* to the ending at 04^h, May 25.

June 14-15—A moderate storm began at $08^h\ 01^m$ GMT, June 14, with a sharp increase in H, followed by a bay in H and moderate disturbance in all elements. It ended at about 11^h, June 15.

June 25-26—A period of moderate disturbance preceded a sudden increase in H of 60 gammas at $02^h\ 54^m$ GMT, June 25. This was followed by a period of rapid variations in H and D and rapid but small changes in Z. The later part of the storm was characterized by the usual bay in H, with the ending at about 10^h, June 26.

ROLAND F. WHITE, *Observer-in-Charge*

HUANCAYO MAGNETIC OBSERVATORY

APRIL TO JUNE, 1940

(*Latitude 12° 02′.7 S., longitude 75° 20′.4 or* $5^h\ 01^m.4$ *W. of Gr.*)

April 1-3—Moderate disturbances were recorded during this period.

April 25-26—There was a sudden commencement at $02^h\ 06^m$ GMT, April 25, which was followed by moderately disturbed conditions through 06^h, April 26.

May 14—There was a sharp increase in horizontal intensity at $17^h\ 48^m$ GMT, May 14, which was associated with a type-2 radio fade-out.

May 23-24—There was a strong sudden commencement at $17^h\ 54^m$ GMT, May 23, which was followed by moderately disturbed conditions throughout May 24.

May 26—There was a minor sudden commencement at $01^h\ 20^m$ GMT, May 26, which was followed by a mild disturbance of short duration.

June 14—A sudden commencement at $08^h\ 01^m$ GMT, June 14, was followed by mildly disturbed conditions through 14^h.

June 25—A sudden commencement at $02^h\ 55^m$ GMT, June 25, was followed by a strong disturbance lasting through 20^h. Approximate range in H was 426 gammas.

H. W. WELLS, *Observer-in-Charge*

APIA OBSERVATORY

APRIL TO JUNE, 1940

(*Latitude 13° 48′.4 S., longitude 171° 46′.5 or* $11^h\ 27^m.1$ *W. of Gr.*)

April 2-3—Disturbance began gradually from 16^h GMT, April 2. After 01^h, April 3, a rapid decrease of 179 gammas occurred in H, a minimum being recorded at $06^h\ 00^m$. The elements remained disturbed during April 3. Sharp oscillations in H and Z with a period of ten minutes occurred at times between 11^h and 22^h. Fluctuation of amplitude 2′ occurred in D between 00^h and 07^h.

April 25—A sudden commencement occurred at $02^h\ 04^m$ GMT, April 25, with an increase of 25 gammas in H and an increase of 11 gammas followed an initial decrease of 1 gamma in the numerical value of Z. H decreased rapidly by 202 gammas between $02^h\ 34^m$ and the minimum of the storm at $04^h\ 41^m$; Z decreased numerically 31 gammas in the same interval. D was noticeably disturbed between 02^h and 07^h. Renewed activity in all elements occurred from 17^h, April 25, until 12^h, April 26.

May 23-24—A sudden commencement occurred at $17^h\ 54^m$ GMT, April 23. H increased 26 gammas while the numerical value of Z increased 8 gammas; D moved easterly 0′.7. An irregular fall in H began at 03^h, May 24, and a minimum was recorded at $11^h\ 19^m$. Range: H, 154 gammas.

June 14—A small sudden commencement occurred at $08^h\ 00^m$ GMT, June 14, with an increase of 13 gammas in H and of 3 gammas in the numerical value of Z. Slight disturbance continued until 10^h, June 15.

June 25-26—A sudden commencement occurred at $02^h\ 53^m$ GMT, June 25. H increased 24 gammas and the numerical value of Z increased 10 gammas. Disturbed conditions continued until 06^h, June 26, with rapid oscillations of small amplitude in H and Z. Large movements occurred in H, Z and D between 10^h and 15^h, June 25. Range: H, 156 gammas.

C. W. Tremewan, *for Acting Director*

Alibag Magnetic Observatory[1]

January to March, 1940

(Latitude 18° 38′.3 N., longitude 72° 52′.3 or $4^h\ 51^m.5$ E. of Gr.)

January 3-4—A moderate storm of short duration began with a sudden commencement at $14^h\ 41^m$ GMT, January 3, with a rise of 22 gammas in H. Attaining its maximum at $14^h\ 50^m$, January 3, H fell rapidly with occasional jumps, reaching its minimum at $17^h\ 01^m$, January 3. Thereafter, H rose and attained its pre-storm value at about $22^h.5$, January 3. Minor fluctuations continued and the storm ended at $04^h.5$, January 4. Ranges: D, 8′.6; H, 203 gammas; Z, 42 gammas.

January 18-19—Another moderate disturbance commenced suddenly at $09^h\ 53^m$ GMT, January 18. H reached its maximum at $10^h\ 01^m$, January 18, and began to fall slowly. The fall became more rapid after $14^h\ 40^m$ and the minimum was reached at $17^h\ 33^m$, January 18. Later, H rose with fluctuations and the storm practically ended at $10^h.5$, January 19. Ranges: D, 4′.9; H, 184 gammas; Z, 45 gammas.

February 24-26—A moderate disturbance began at $22^h\ 12^m$ GMT, February 24, with a sudden rise of 25 gammas in H. H fell for about five hours and then began to rise gradually, reaching its maximum at $07^h\ 16^m$, January 25. Thereafter, H fell and rose with fluctuations and the minimum was reached at $18^h\ 03^m$, January 25. The oscillations became feebler later on and the storm ended at $21^h.5$, January 26. Ranges: D, 4′.6; H, 150 gammas; Z, 62 gammas.

March 24-25—A very severe storm commenced at $13^h\ 50^m$ GMT, March 24, with a sudden rise of 1′.3 in westerly D, and 62 gammas in H and a fall of 10 gammas in Z. This is the severest storm recorded here during the last 70 years. At $15^h\ 45^m$, March 24, H and D rose by 321 gammas and 8′.3 (westerly), respectively. H attained its maximum at $15^h\ 46^m$, March 24, which was followed by a sudden fall of 500 gammas in 36 minutes. At $16^h\ 33^m$, March 24, H went off the photographic sheet and was brought within the field at $17^h\ 08^m$, March 24, by the use of a deflector-magnet. Again, H fell and was off the sheet between $17^h\ 40^m$ and $18^h\ 04^m$, March 24, in spite of the deflector-magnet. The

[1]Communicated by Dr. S. R. Savur, Director, Bombay and Alibag Observatories.

most disturbed period during the storm was between $15^h\ 45^m$ and $19^h\ 03^m$, March 24, when telegraphic transmission throughout the world was crippled. On March 25, the Solar Physics Observatory at Kodaikanal observed a large sunspot-group approaching the central meridian. Pronounced oscillations in *H* continued from $18^h\ 18^m$ to $19^h\ 18^m$, March 24, when they became feebler. At $21^h\ 04^m$, March 24, *H* rose with fluctuations and began to fall from $21^h\ 56^m$, March 24. Minor fluctuations continued till $00^h\ 03^m$, March 25, when conditions became more disturbed once again. At $11^h\ 06^m$, March 25, *H* began to recover gradually and the storm ended at about $18^h.5$, March 25. Ranges: *D*, 17′.1; *H*, >785 gammas; *Z*, >100 gammas.

March 29-31—A storm of great intensity began at $16^h\ 02^m$ GMT, March 29, with a sudden rise of 1′.3 in westerly *D*, and 55 gammas in *H* and a fall of 15 gammas in *Z*. At $16^h\ 26^m$, March 29, *H* began to fall rapidly and with occasional fluctuations reached a sharp minimum at $19^h\ 10^m$, March 29, after which it rose. At $23^h\ 17^m$, March 29, there was a steep rise of 185 gammas in *H* in 36 minutes. From $00^h\ 18^m$, March 30, conditions became more disturbed and continued so till $15^h\ 46^m$, March 30, after which they became quieter. The storm practically ended at $02^h.5$, March 31, though minor fluctuations continued. Ranges: *D*, 7′.9; *H*, 266 gammas; *Z*, 74 gammas.

March 31-April 2—Another disturbance of great intensity began with a sudden commencement at $09^h\ 42^m$ GMT, March 31, with an abrupt rise of 36 gammas in *H*. Attaining its maximum at $09^h\ 46^m$, March 31, *H* fell rapidly with occasional fluctuations. The minimum in *H* occurred at $11^h\ 44^m$, March 31. Conditions were very disturbed till 20^h, March 31, after which the oscillations became smaller. The disturbance ended at $22^h.5$, April 2. Ranges: *D*, 5′.9; *H*, 242 gammas; *Z*, 41 gammas.

Department of Terrestrial Magnetism,
Bombay Observatory, India M. R. Rangaswami

Watheroo Magnetic Observatory

March to June, 1940

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h\ 43^m.5$ E. of Gr.)

March 23-28—This disturbance, of major importance, began at $06^h\ 16^m$ GMT, March 23, with rather sudden movements in all three elements; *H* increased by 27 gammas, the corresponding movements in *Z* and *D* were quite small. Apart from a brief period of activity between $09^h\ 10^m$ and $09^h\ 20^m$ on the same day, the traces were only moderately disturbed during the ensuing 30 hours; an interesting feature, however, was the increasing rapidity of the fluctuations, though of small amplitude, after 00^h, March 24. At $13^h\ 49^m$, March 24, the main activity of the storm was heralded by a sudden commencement, where the *H* increased by 55 gammas, the *Z* decreased by about 7 gammas and the westerly declination decreased by about 2′. Thereafter the fluctuations became so violent that some of the movements were too rapid to record; it is probable, however, that the maximum intensity of the disturbance was at about 01^h, March 25, when the horizontal intensity reached a value about 500 gammas lower than the normal, this representing a decrease of over two per cent in the force. These rapid and violent fluctuations

continued until about noon, March 25, after which the activity was very much reduced and without any noteworthy feature except for a pronounced "bay" at 19^h 30^m, March 26. Throughout March 27 and 28 the traces were slightly disturbed but were gradually resuming their normal values. The aurora was observed in and around Perth at intervals between 17^h and 20^h, March 24. Ranges: D, 45′; H, 685 gammas; Z, indefinite, but greater than 300 gammas.

March 29-April 1—This disturbance, of more than moderate intensity, may probably be considered to be a later phase of the one which is described above and which subsided before 24^h GMT, March 28. There were signs of increasing activity in the curves after 09^h, March 29, with a prominent "bay" at 12^h 18^m. At 16^h 03^m, March 29, there appeared what would normally be considered a sudden commencement, H increasing very suddenly by 66 gammas. The next feature was a succession of "peaks" and "bays" between 17^h 39^m and 19^h 00^m on the same day, during which the declination covered a range of 35′. During this time the value of H began to decrease and reached a minimum value at 04^h 37^m, March 30—355 gammas below the normal. The traces continued to be moderately disturbed through March 31 and it was not until 21^h, April 1, that they resumed their normal characters. Ranges: D, 51′; H, 365 gammas; Z, 271 gammas.

April 2-4—This moderate disturbance was probably a continuation of the magnetic storm previously reported as having ended at 21^h GMT, April 1. No sudden commencement was evident and the traces gradually became disturbed after 16^h, April 2. The main activity was shown between 01^h and 08^h, April 3, when the movements were of moderate amplitude and rather rapid fluctuations were the main features. A further brief period of activity was around 20^h, April 3, this phase only lasting for about 30 minutes. After this time the traces gradually resumed their normal appearance, quiet conditions being regained by 18^h, April 4 Ranges: D, 12′.1; H, 230 gammas; Z, 104 gammas.

April 25-26—A moderate disturbance began with a sudden commencement shown in all three elements at 02^h 03^m GMT, April 25 H increased by 20 gammas in six minutes, Z increased by 11 gammas, and the westerly declination increased by 3′.3. Thereafter the fluctuations were of a rapid type and of small amplitude, except in H which showed a large bay between 02^h and 06^h, the maximum depression of H occurring at 04^h 16^m when the force was 140 gammas less than that prevailing before the disturbance. The variations in the elements after 06^h, April 25, were quite moderate and do not merit detailed description but normal conditions were not resumed before 21^h, April 26. Ranges: D, 15′.8; H, 167 gammas; Z, 87 gammas.

May 23-24—This small disturbance began at 17^h 53^m GMT, May 23, with a sudden commencement shown in all three elements. H increased 29 gammas in three minutes, Z decreased by 23 gammas and the westerly declination decreased by 3′.5. A quiet period ensued, but at 03^h, May 24, sweeping movements began which continued until 21^h on the same day, after which normal conditions were resumed. Ranges: D, 13′.6; H, 160 gammas; Z, 110 gammas.

June 25-26, 1940—This moderate disturbance began abruptly at 02^h 53^m GMT, June 25, although the traces for the preceding 24 hours

had been slightly irregular. The sudden commencement was shown in all three elements and the initial movement was so rapid that, in the case of the horizontal and vertical intensities, it failed to record itself on the photographic trace. However, the extent and direction of the impulse are worthy of note; the horizontal intensity decreased by 27 gammas, the vertical intensity increased 24 gammas and the westerly declination increased by 5′.8—these movements were in each case in the opposite sense to those usually experienced at Watheroo at the commencement of a magnetic "storm." Another unusual feature of the disturbance was that rapid fluctuations of considerable amplitude followed immediately on the initial impulse and continued for about 40 minutes, the range in horizontal intensity during this time amounting to 126 gammas. For the ensuing six hours the movements were still of short period, but of small amplitude until at 10^h, June 25, large sweeping changes in the elements prevailed, continuing thus until 20^h. From that time on, until 07^h, June 26, the movements were small but rapid and disturbed conditions had ceased by 08^h, June 26. Ranges: D, 31′.0; H, 198 gammas; Z, 180 gammas.

W. C. Parkinson, *Observer-in-Charge*

NOTES

18. *Apia Observatory, Samoa*—The new building for absolute magnetic observations at the Apia Observatory, Samoa, was completed in March 1940.

19. *Cheltenham Magnetic Observatory*—The insulation of the east wing at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey has been completed. Eight inches of fiber-glass and several inches of celotex insulation were added to the four sides, floor, and ceiling of the absolute room. Double doors and covers over wall-openings for mark-readings were added, the latter being filled with fiber-glass. As yet, thermostatic temperature-control equipment has not been installed, but it is intended that this be done soon. This work is preparatory to the installation of the new electromagnetic standard being constructed at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

Before and after completion of the above-described constructional work, surveys of station-differences for practically all piers at Cheltenham were made. Magnetometers were used for D, QHM's for H, and an Askania for Z.

Advantage was taken of the new insulated room to recalibrate the three QHM's belonging to the United States Coast and Geodetic Survey, with special emphasis on the temperature-coefficients. These had been found to be slightly off in connection with field-work done in Florida early in 1939. Subsequent observations have confirmed this fact, and the observations just completed will correct these discrepancies.

Pier 7 in the east wing has been rebuilt, maintaining the azimuths from the original pier. Declinometer No. 26 has been removed, and magnetometer No. 37 operating on Pier 7 is now the standard of the Observatory for declination. Final differences between the two instruments have not yet been obtained, although the necessary observations have been made.

20. *Sitka Magnetic Observatory*—Construction work at the new Sitka Magnetic Observatory of the United States Coast and Geodetic Survey progressed according to schedule. The piers were placed in the variation-building, and good progress was made on the office and various quarters-buildings.

21. *Grant for gravimeter traverse*—Among the grants in support of special research projects authorized by the council of the Geological Society of America at its meeting in April, 1940, was one of $3,000 to George P. Woollard, Fellow, National Research Council, Princeton, New Jersey, who is starting a gravimeter traverse which is expected to complete a line from Washington, D. C., to Los Angeles. Data on the Washington to Pittsburgh portion of the traverse are already available. The gravimeter has been made available by the Humble Oil and Refining

Company. The study should yield knowledge of the fundamental structure of North America comparable to that relative to the structure of island-arcs provided by the work of Vening Meinesz and collaborators. It is a study by gravitational, geological, and magnetic methods of the deeper parts of the Earth's crust and the relations of anomalies to continental structure. The work will continue throughout the coming summer.

22. *Cosmic-ray symposium*—Among the fourteen principal symposia held at the Seattle meeting (June 17-22, 1940) of the American Association for the Advancement of Science, was one on cosmic rays organized by the American Physical Society, in which H. A. Bethe, A. H. Compton, and R. A. Millikan were scheduled participants.

23. *Corrigendum*—In the June 1940 number of the JOURNAL in the article by J. M. Sil and K. S. Agarwala on page 139, the last sentence of the third paragraph should read "14 mm per hour" instead of "14.7 mm per hour."

24. *Personalia*—*R. G. Madill* has been placed in charge of the magnetic field-work conducted by the Dominion Observatory, Ottawa, Canada. *C. A. French*, for many years associated with the magnetic work of the Observatory, has been retired.

Effective July 1, 1940, *Roland F. White* relieved *John Hershberger* as Observer-in-Charge at the Tucson Magnetic Observatory of the United States Coast and Geodetic Survey. Mr. Hershberger started August 1 on magnetic field-work in New England, reoccupying repeat-stations in that area, with particular emphasis on declination. *Joel B. Campbell* continues to occupy repeat-stations in the middle, far, and southwestern portions of the United States. Among these were two new repeat-stations in the vicinity of Seattle, Washington. *David G. Knapp* has returned to the Washington Office of the United States Coast and Geodetic Survey, having been in charge of magnetic computing at the New York WPA Computing Office for the past two years. Commander *H. A. Cotton* has taken over this work in New York.

Professor *Adolf Schmidt* completed his eightieth year on July 23, 1940, at his home in Gotha (Germany), where he has lived since retirement from his post as Director of the Potsdam Magnetic Observatory. His many friends in all parts of the world will join this JOURNAL, which enjoys his collaboration as a contributing editor, in extending hearty greetings. The treatise "Geomagnetism" by Chapman and Bartels, so appropriately dedicated to Professor Schmidt, appeared shortly before his birthday.

H. F. Skey retired from the directorship of the Christchurch Magnetic Observatory, May 31, 1940, being succeeded in that post by *H. F. Baird*.

The JOURNAL regrets to learn that *D. C. Jones*, Observer-in-charge, Puerto Rico Magnetic Observatory, of the United States Coast and Geodetic Survey since March 7, 1940, died suddenly at San Juan, August 15, 1940, aged 52 years.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Alfvén, H. A theory of magnetic storms and of the aurorae. II. The aurorae. III. The magnetic disturbances. Stockholm, Vet.-Ak. Handl., **18**, No. 9, 39 pp. (1940).

Bramhall, E. H. Magnetic observations in Alaska, July-August, 1939. Field Eng. Bull., U. S. Coast Geod. Surv., No. 13, 175-186 (Dec. 1939). [Extracts from Dr. Bramhall's 1939 season's report.]

Burger, A. Potsdamer erdmagnetische Kennziffern. 6. Mitteilung. Zs. Geophysik, **16**, Heft 1/2, 85-86 (1940). [August bis Oktober 1939.]

Chapman, S., and J. C. P. Miller. The statistical determination of lunar daily variations in geomagnetic and meteorological elements. Mon. Not. R. Astr. Soc., Geophys. Sup., **4**, 649-669 (1940).

Coutrez, G. Tempête magnétique et aurore boréale du 24 mars 1940. Ciel et Terre, **56**, No. 5, 253-254 (1940). [Brief note.]

Eblé, L., G. Gibault, et E. Tabesse. Sur la perturbation magnétique du 24 mars 1940. Paris, C.-R. Acad. sci., **210**, No. 15, 542-543 (1940).

Egypt, Physical Department. Meteorological report for the year 1934. Cairo, Ministry of Public Works, Physical Dept., xiv + 235 (1940). 32 cm. [Contains values of the magnetic elements at Helwan Observatory for 1934.]

Fleming, J. A. The great magnetic storm. Sci. Mon., **50**, No. 5, 475-480 (1940), [Description of the magnetic storm of Easter Sunday, March 24, 1940.]

Wide-range magnetograph at Washington, D. C. Terr. Mag., **45**, No. 2, 213-214 (1940).

Godart, O. On space closure of periodic orbits in the field of a magnetic dipole. Abstract, Phys. Rev., **57**, 1062-1063 (1940).

Hatakeyama, H. On the bay-disturbance in the terrestrial magnetic field. Geophys. Mag., Tokyo, **12**, No. 1/2, 15-66 (1938).

On the pulsation of the terrestrial magnetic field. Geophys. Mag., Tokyo, **12**, No. 3, 173-188 (1938).

On the bay-disturbance and the pulsation of the earth-current. Geophys. Mag., Tokyo, **12**, No. 3, 189-210 (1938).

Inglis, D. R., and E. Teller. On a proposed thermoelectric origin of the Earth's magnetism. Phys. Rev., **57**, No. 12, 1154-1155 (1940). [It has been suggested that the Earth's magnetism might arise from thermoelectric forces within the Earth, the asymmetrical thermal distribution being due to material convection guided by Coriolis forces from the Earth's rotation. The observed heat flow through the crust so limits the possible velocities and temperature differences that the Coriolis force seems to be inadequate by about a factor 10^6.]

Isaev, S. I. Magnetic observations on the drift of the *Sedov* from March 27 to August 27, 1938. Problemi Arktiki, Leningrad, No. 9, 83-88 (1940). [Russian text. In addition to the discussion of the magnetic work, a table containing the magnetic results obtained at the 32 stations where observations were made, is given on pp. 86-88.]

Lahaye, E. La déclinaison magnétique à Uccle en janvier 1940. Ciel et Terre, **56**, No. 4, 164 (1940).

La déclinaison magnétique à Uccle en février 1940. Ciel et Terre, **56**, No. 5, 250-251 (1940).

La tempête magnétique des 24 et 25 mars 1940. Ciel et Terre, **56**, No. 5, 235-241 (1940). [Phénomènes magnétiques, auroraux, ionosphériques, et solaires.]

LOGACHEV, A. A. Magnitnaia c'emka v dvizhenii. Izv. Gos. Gecgr. Obšč., **71**, No. 6, 897-901 (1940). [Le levé magnétométrique ambulant. Texte russe.]

LOUGHRIDGE, D. H., AND P. F. GAST. Magnetic storm effect of cosmic rays at high latitudes. Phys. Rev., **57**, No. 10, 938 (1940).

LOVÖ. Ergebnisse der Beobachtungen des magnetischen Observatoriums zu Lovö, (Stockholm) im Jahre 1935. Von Sven Åslund. Stockholm, Kungl. Sjökarteverket, 103 pp. (1940). 32 cm.

LÜDERS, K. Die Ablenkung (Deviation) der Kompassnadel in Strömungsmessern mit magnetischer Richtungsangabe. Ann. Hydrogr., **68**, Heft 5, 163-179 (1940).

MCNISH, A. G. Physical representation of the geomagnetic field. Abstract, Phys. Rev., **57**, No. 11, 1088 (1940).

Note on scale-value equation of the CIW induction-variometer. Terr. Mag., **45**, No. 2, 223-224 (1940).

NAGATA, T. Some physical properties of the lavas of volcanoes Asamà and Mihara. II. Magnetic susceptibility. Bull. Earthquake Res. Inst., Tokyo Imp. Univ., **18**, pt. 1, 102-135 (1940). [English text with Japanese summary.]

NICHOLSON, S. B. The great magnetic storm of March 24, 1940. Pub. Astr. Soc. Pacific, **52**, 169-171 (1940).

PARIS, BUREAU DES LONGITUDES. Annuaire pour l'an 1940 avec des notices scientifiques. Paris, Gauthier-Villars, 549+A.16+B.25+C.53 (1940). [Contains brief article on atmospheric electricity, pp. 174-175; isogonic map of France for epoch 1940.0; and tables of magnetic declination at various stations in France and her colonies reduced to epoch 1940.0. A table of mean annual values of declination for observatories in all parts of the world is given on pages 185-186.]

PRINCIPAL MAGNETIC STORMS. January to March, 1940. Terr. Mag., **45**, No. 2, 226-234 (1940). [Storms reported by Alibag and Capetown magnetic observatories are for October to December, 1939.]

RICHARDSON L. A., J. M. RAYNER, AND P. B. NYE. Second report on magnetic prospecting at Tennant Creek (1936). Canberra, Aerial Geol. Geophys. Surv. N. Australia, 11 pp., 5 pls. (1939). [Report, Northern Territory No. 23 (supplementary to Northern Territory No. 4).]

ROWLAND, J. P. Aurora and magnetic storm of March 24-25 [1940]. Nature, **145**, 625-626 (Apr. 20, 1940).

RUSSELL, H. N. What causes magnetic storms? Sci. Amer., **162**, No. 6, 332-333 (1940).

SMESOV, A. Magnetic observations on the *Nerpa*. Problemi Arktiki, Leningrad, No. 9, 88-89 (1940). [Russian text. Results of magnetic declination-observations obtained at seven stations in the summer of 1939.]

B—Terrestrial and Cosmical Electricity

AGENO, M., G. BERNARDINI, N. B. CACCIAPUOTI, B. FERRETTI, AND G. C. WICK. The anomalous absorption of the hard component of cosmic rays in air. Phys. Rev., **57**, No. 11, 945-950 (1940).

ALLEN, C. W. Potential gradient observations at Mount Stromlo during 1933-1938. Mem. Solar Obs., Mt. Stromlo, Canberra. No. 8 [**2**, No. 3], 34 pp. (1939).

AURORA. Nordlicht 1940, Januar 3. Zs. Geophysik, **16**, Heft 1/2, 88-89 (1940). [Four brief notes by C. Fedtke, K. Liebermann, H. Bärnreuther, and C. Hoffmeister.]

BARNÓTHY, J. Die durchdringende Strahlung hinter mehr als 300 m Wasseräquivalent. Zs. Physik, **115**, Heft 3/4, 140-149 (1940).

BOSS, L. J. The aurora of March 24, 1940. Pop. Astr., **48**, No. 5, 282-283 (1940)

C., H. E. Auroral notes, November 1939 to January 1940. Met. Mag., **75**, No. 891, 52-54 (1940).

Cosyns, M. G. E. Barometric coefficient of extensive cosmic ray showers. Nature, London, **145**, 668 (Apr. 27, 1940).

Ehmert, A. Ueber die Zwölfstundenperiode der Mesotronintensität und die Höhe des Ursprungs der Mesotronen. Naturwiss., **28**, Heft 2, 28-29 (1940).

Ueber die harte Komponente der kosmischen Strahlung in der Stratosphäre. Zs. Physik, **115**, Heft 5, 6, 326-332 (1940).

Ueber die Zerfallswahrscheinlichkeit des Mesons. Zs. Physik, **115**, Heft 5/6, 333-338 (1940).

Euler, H. Ueber die Beobachtung von Luftschauern und Kernzertrümmerungen der kosmischen Strahlung in der Ionisationskammer. Naturwiss., **28**, Heft 9, 141-142 (1940).

Fedchenko, K. K. Zemnie toki i ikh sviaz c zemnim magnetizmom. Problemi Arktiki, Leningrad, No. 9, 55-61 (1940). [Earth-currents and their relation with terrestrial magnetism.]

Geddes, M. Catalogue of aurora australis displays, 1931-1938. Trans. R. Soc. N. Zealand, **69**, pt. 4, 381-391 (1940).

Gish, O. H., and K. L. Sherman. Analysis of local atmospheric-electric phenomena at College, Alaska. Terr. Mag., **45**, No. 2, 173-190 (1940).

Hagengut, J. H. Lightning recording instruments. Gen. Elec. Rev., **43**, 195-201, 248-255 (1940). [Part I. Instruments developed for studies of natural lightning. Notable application at Empire State Building. Features of design, operation, and performance. Part II. Oscillograph for measuring currents of low amplitude and long duration. Shunt of crater-lamp oscillograph. Photographic equipment. High-speed camera. Slow-speed camera.]

Hess, V. F. On the seasonal and atmospheric temperature effect in cosmic radiation. Phys. Rev., **57**, No. 9, 781-785 (1940).

Johnson, T. H., J. G. Barry, and R. P. Shutt. Direct evidence of a proton component of the cosmic radiation. Phys. Rev., **57**, No. 11, 1047-1048 (1940).

Korff, S. A. On the contribution to the ionization at sea-level produced by the neutrons in the cosmic radiation. Terr. Mag., **45**, No. 2, 133-134 (1940).

Minser, E. J. Meteorological conditions associated with aircraft lightning discharges and atmospherics. J. Aeron. Sci., **7**, No. 2, 51-55 (1939). Abstract Bull. Amer. Met. Soc., **21**, No. 5, 200-202 (1940).

Mukherji, S. M., and A. R. Pillai. The electrical characterization of days at Colaba (Bombay, India) during 1930-38. Terr. Mag., **45**, No. 2, 135-138 (1940).

Newton, H. W. The active solar and magnetic period 1940 March 20 to April 2. Observatory, **63**, No. 792, 129-134 (1940).

Nishina, Y., Y. Sekido, H. Simamura, and H. Arakawa. Cosmic ray intensities and cyclones. Nature, **145**, 703-704 (May 4, 1940).

Air mass effect on cosmic radiation. Phys. Rev., **57**, No. 11, 1050-1051 (1940).

Nordsieck, A., W. E. Lamb, Jr., and G. E. Uhlenbeck. On the theory of cosmic-ray showers I. The Furry model and the fluctuation problem. Physica, **7**, No. 4, 344-360 (1940).

Owens, J. S. Sea-salt and condensation nuclei. Q. J. R. Met. Soc., **66**, No. 283, 2 (1940).

Pekeris, C. L. The vertical distribution of ionization in the upper atmosphere. Terr. Mag., **45**, No. 2, 205-211 (1940).

Regener, E., und W. Rau. Ueber Schwankungen der harten Komponente der kosmischen Strahlung. Naturwiss., **27**, Heft 48, 803-805 (1939).

Salles, Ed. Les recherches entreprises sur l'électricité atmosphérique à l'Observatoire de Chambon. J. Phys. et Le Radium, Sér. 8, **1**, 26S-28S (1940).

Schein, M., W. P. Jesse, and E. O. Wollan. Intensity and rate of production of mesotrons in the stratosphere. Phys. Rev., **57**, No. 10, 847-854 (1940).

SELS, H. K., AND A. W. GOTHBERG. Lightning protection of wood-pole lines. Elec. Eng., **59**, No. 6, 328-331 (1940).

SHERMAN, K. L. Total and uncharged nuclei at Washington, D. C. Terr. Mag., **45**, No. 2, 191-204 (1940).

SIL, J. M., AND K. S. AGARWALA. The atmospheric potential-gradient at Poona, India. Terr. Mag., **45**, No. 2, 139-144 (1940).

STEINKE, E. G., UND H. SCHMID. Hoffmannsche Stösse und Multiplikationstheorie. Naturwiss., **28**, Heft 6, 93-94 (1940).

STEWART, G. Three auroral displays in 1939. Q. J. R. Met. Soc., **66**, No. 283, 80-81 (1940).

SWANN, W. F. G., AND W. E. RAMSEY. Shower production by mesotrons in different materials. Phys. Rev., **57**, No. 8, 749 (1940).

Further evidence for the existence of mesotron showers. Phys. Rev., **57**, No. 11, 1051 (1940).

TERADA, K. Electromagnetic induction within the Earth's crust of variable conductivity. (Part I). Geophys. Mag., Tokyo, **13**, No. 1, 63-104 (1939).

WEBER, E. Versuche zur Absolutbestimmung der Höhenstrahlenkoinzidenzen mit einem Verstärker vorgebbaren Auflösungsvermögens. Physik. Zs., **41**, No. 9/10, 242-256 (1940).

WIDHALM, A. Schwere Teilchen in der kosmischen Höhenstrahlung. Zs. Physik, **115**, Heft 7/8, 481-496 (1940).

WRIGHT, H. L. Sea-salt nuclei. Q. J. R. Met. Soc., **66**, No. 283, 3-11 (1940).

The origin of sea-salt nuclei. Q. J. R. Met. Soc., **66**, No. 283, 11-12 (1940).

YUNKER, E. A. The diurnal variation and vertical distribution of atmospheric condensation-nuclei. Terr. Mag., **45**, No. 2, 121-126 (1940).

The mobility-spectrum of atmospheric ions. Terr. Mag., **45**, No. 2, 127-132 (1940).

C—Miscellaneous

A., L. Le Père Luis Rodés. Bull. Soc. Astr. France, **54**, 86-87 (1940).

APPLETON, E. V., AND W. J. G. BEYNON. The application of ionospheric data to radio-communication problems: Part I. Proc. Phys. Soc., **52**, No. 292, 518-533 (1940).

APPLETON, E. V., AND R. NAISMITH. Normal and abnormal region-E ionisation. Proc. Phys. Soc., **52**, No. 291, 402-415 (1940).

BALDWIN, J. M. The magnetic observatory at Toolangi. Terr. Mag., **45**, No. 2, 214 (1940).

BHAR, J. N. Studies of the ionosphere at Calcutta. Indian J. Phys., **13**, pt. 4, 253-276, 21 figs. (1939).

BRUNNER, W. Provisional sunspot-numbers for January to April, 1940. Terr. Mag., **45**, No. 2, 166 (1940).

CROWDER, W. Marvels of the night. Sci. Amer., **162**, No. 6, 338-340 (1940). [The aurora, zodiacal light, and bizarre types of lunar halos.]

DARROW, K. K. The ionosphere. Elec. Eng., **59**, No. 7, 272-283 (1940). [Review of current facts and theories of the ionosphere.]

DITTRICH, W. W. Untersuchungen über Doppel-Koinzidenzanordnungen. Physik. Zs., **41**, No. 9/10, 256-269 (1940).

ELLISON, M. A. Solar and terrestrial relationships of March 23-29, 1940. Nature, **145**, 898 (June 8, 1940).

F., G. C., ET F. Q. Eruption solaire, perturbation magnétique et aurore boréale. Bull. Soc. Astr. France, **54**, 88-89 (1940).

FARMER, F. T., AND H. B. MOHANTY. The velocity of propagation of wireless waves over the ground. Proc. Phys. Soc., **52**, No. 292, 456-463 (1940).

Fleming, J. A. Washington Assembly of the International Union of Geodesy and Geophysics and the American Geophysical Union. Science, **91**, 439-442 (May 10, 1940).

Gilliland, T. R., S. S. Kirby, and N. Smith. Characteristics of the ionosphere at Washington, D. C., February, 1940, with predictions for May, 1940. Proc. Inst. Radio Eng., **28**, No. 4, 191-192 (1940).

Characteristics of the ionosphere at Washington, D. C., March, 1940, with predictions for June, 1940. Proc. Inst. Radio Eng., **28**, No. 5, 236-238 (1940).

Goodall, W. M. Midday F_2-region critical frequencies for Deal, New Jersey. Terr. Mag., **45**, No. 2, 222-223 (1940).

Harang, L. Annual variations of the critical frequencies of the ionized layers at Tromsö during 1939. Terr. Mag., **45**, No. 2, 167-168 (1940).

Harradon, H. D. The Eighth American Scientific Congress. Terr. Mag., **45**, No. 2, 220-222 (1940).

List of recent publications. Terr. Mag., **45**, No. 2, 238-243 (1940).

Johnston, H. F. American *URSI* broadcasts of cosmic data, with American magnetic character-figure C_A, January to March, 1940. Terr. Mag., **45**, No. 2, 214-218 (1940).

Lejay, P. Recherches sur l'ionosphère à Shanghai. Onde Electrique, **19**, No. 217/218, 8-38, 7 pls. (1940).

Löwy, H. Electrodynamic hydrology. Terr. Mag., **45**, No. 2, 149-154 (1940).

Mauchly, J. W. A significance-test for ellipticity in the harmonic dial. Terr. Mag., **45**, No. 2, 145-148 (1940).

Mount Wilson Observatory. Summary of Mount Wilson magnetic observations of sunspots for January to April, 1940. Pub. Astr. Soc. Pacific, **52**, 148-151, 209-211 (1940).

National Bureau of Standards. Averages of critical frequencies and virtual heights of the ionosphere, observed by the National Bureau of Standards at Washington, D. C., January to March, 1940. Terr. Mag., **45**, No. 2, 224-225 (1940).

Nicholson, S. B., and E. S. Mulders. Provisional solar and magnetic character-figures, Mount Wilson Observatory, January to March, 1940. Terr. Mag., **45**, No. 2, 218-220 (1940).

Parkinson, W. C., and S. L. Prior. The ionosphere at Watheroo, Western Australia, October to December, 1939. Terr. Mag., **45**, No. 2, 169-172 (1940).

Reichelderfer, F. W. The contributions of Wilkes to terrestrial magnetism, gravity, and meteorology. Proc. Amer. Phil. Soc., **82**, No. 5, 583-600 (1940).

Stoodley, L. G. Radio wave reflections in the troposphere. Nature, **145**, 743 (May 11, 1940).

Teller, E., and M. A. Tuve. The sixth Washington conference on theoretical physics, March 21-23, 1940. Science, **91**, 621-623 (June 28, 1940).

Wells, H. W., and R. C. Coile. The ionosphere at Huancayo, Peru, October to December, 1939. Terr. Mag., **45**, No. 2, 155-158 (1940).

Ionospheric characteristics at Huancayo, Peru, for the year 1939. Terr. Mag., **45**, No. 2, 159-165 (1940).

Wilkes, M. V. The theory of reflexion of very long wireless waves from the ionosphere. Proc. R. Soc., A, **175**, No. 961, 143-163 (1940).

Williams, S. R. Correlation between hardness and the magnetic properties of solid matter. Instruments, **13**, No. 7, 188-194 (1940).

Wright, H. L. Atmospheric opacity at Valentia. Q. J. R. Met. Soc., **66**, No. 283, 66-77 (1940).

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IONOSPHERIC CHANGES ASSOCIATED WITH THE MAGNETIC STORM OF MARCH 24, 1940

By L. V. Berkner and S. L. Seaton

Abstract—Observations of the ionosphere at the Huancayo and Watheroo magnetic observatories during the great magnetic disturbance of March 24, 1940, are shown and discussed. At Huancayo, the ionospheric disturbance began about 40 minutes before the first really large magnetic change, though coinciding with increasing magnetic activity. During the first great magnetic changes, the F_2-layer was swept upward and disappeared in about 30 minutes. At the same time, ion-density of the E-layer rose about 40 per cent.

Growth of a "new" F_2-layer began after disappearance of the old, proceeding in an apparently normal manner for the next hour. Because the original ion-density had been reduced to a low value, the F_2-region is regarded as a nearly un-ionized atmosphere, suddenly exposed to solar radiation. Effective recombination-coefficient and rate of ion-production at level of maximum density of F_2- region are estimated from this growth. This yields approximate values of $\alpha=1.8\times10^{-10}$ and $q_0=230$. These values must be somewhat larger, and must increase downward, if height-change during growth of the layer is to be explained without electron-transport during the interval.

Steady growth of the new F_2-layer was followed by a succession of abnormal increases and decreases of ion-density of diminishing amplitude at an almost regular period of three hours for three and one-half or four periods. Abnormal rate of decrease and subsequent increase of abnormal electron-production at level of maximum is computed for the first period. This varies between -1000 and $+1700$ electrons per cc per second.

At Watheroo Magnetic Observatory ionospheric changes followed the general pattern usually experienced during magnetic disturbances in temperate zones. Evidence indicates large spatial tilts of iso-ionic surfaces near Watheroo about 40 minutes after beginning of great magnetic changes. These spatial tilts were followed by rapid rise of height and increase of scattering.

Abnormal decrease of ion-density of the F_2-layer at both observatories began simultaneously, within observational limits, less than 15 minutes after the first great geomagnetic change. The great rise in height at Watheroo lagged behind that at Huancayo by nearly an hour. A chronology of radio fade-outs and bright chromospheric eruptions before and during the storm is given.

§ 1. *Introduction*

One of the most violent magnetic storms yet recorded occurred on March 24, 1940. A detailed description of this storm, supplemented by actual records, may be found in "Principal magnetic storms" published regularly in this JOURNAL [see 1 of "References" at end of paper]. Contemporary disturbances to power- and communication-services have been described by McNish [2]. The intense portion of the storm was preceded by a moderate disturbance beginning with a sudden commencement at about $06^h\ 16^m$ GMT, March 23. With a second sudden commencement at about $13^h\ 49^m$ GMT, March 24, movement of the magnetic elements became more pronounced, and at $15^h\ 41^m.5$ the intense era of the storm began when, at Huancayo, the horizontal intensity increased about 1000 gammas in a little more than three minutes. At the same time changes of great range were recorded at other observatories. Violent

fluctuations continued until about 11^h GMT, March 25, when the disturbance subsided to moderate intensity. The interval from $15^h 41^m$, March 24, to 11^h, March 25, contained some of the most violent geomagnetic fluctuations ever observed.

Observation of the ionosphere was complete at both Huancayo and Watheroo magnetic observatories during this time. Photographic records showing ion-distribution as a function of virtual height were taken each quarter-hour using the automatic multifrequency radio technique which has been described elsewhere in detail [3, 4]. Multifrequency observations were over the wave-frequency range of 0.5 to 16.0 mc/sec. In addition virtual height for the wave-frequency 4.8 mc/sec was recorded continuously. These records provide a chronology of changes in the ionosphere before, during, and after the magnetic storm.*

The Huancayo Magnetic Observatory is at the magnetic equator in

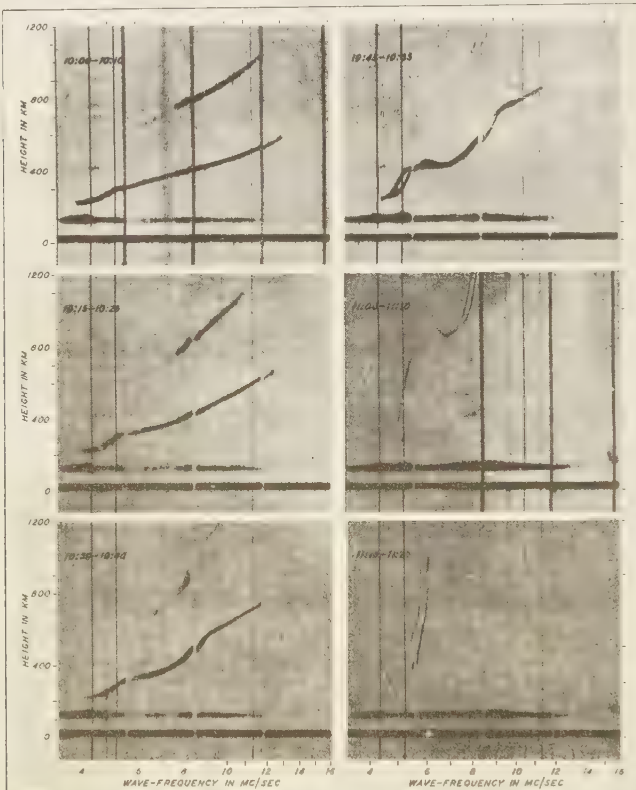


FIG. 1A—IONOSPHERIC RECORDS ILLUSTRATING CHANGES DURING MAGNETIC STORM OF MARCH 24, 1940, AND SHOWING DISAPPEARANCE OF F_2-REGION, HUANCAYO MAGNETIC OBSERVATORY (12°S, 75°W)

*In computing electron-densities from the penetration-frequency of the *o* wave-component, it is assumed that the Lorentz polarization-correction is zero, so that $N = 1.24 \times 10^4 f^2$, where f is given in mc/sec.

the Peruvian Andes (latitude 12° 02′.7 south, longitude 75° 20′.4 west) while the Watheroo Magnetic Observatory is located near the western extremity of Australia (latitude 30° 19′.1 south, longitude 115° 52′.6 east). The difference in local time at the two stations is about 11 (or 13) hours. The apparatus and technique of observation at both stations are practically identical [4]. Timing of measurements on each wave-frequency throughout the range is maintained to within two seconds by means of precision-controls. The advent of this magnetic storm permits accurate time-comparison of commencement of the ionospheric disturbance in the two widely separated localities—the onset of intense geomagnetic disturbance ($15^h 41^m.5$ GMT) occurred near noon at Huancayo, and near midnight at Watheroo. Other unusual features of the observed data suggest that a detailed representation and discussion of these observations might prove profitable.

In § 2, the observations at Huancayo are presented in detail, with records showing the most severe ionospheric changes. Condensed figures

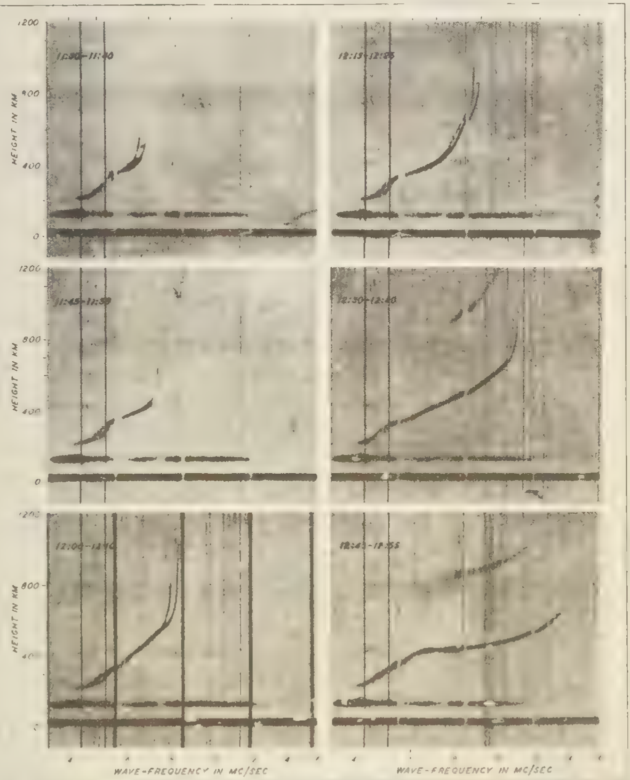


FIG. 18—IONOSPHERIC RECORDS ILLUSTRATING CHANGES DURING MAGNETIC STORM OF MARCH 24, 1940, AND SHOWING PRODUCTION OF NEW F_2-REGION, HUANCAYO MAGNETIC OBSERVATORY (12°S, 75°W)

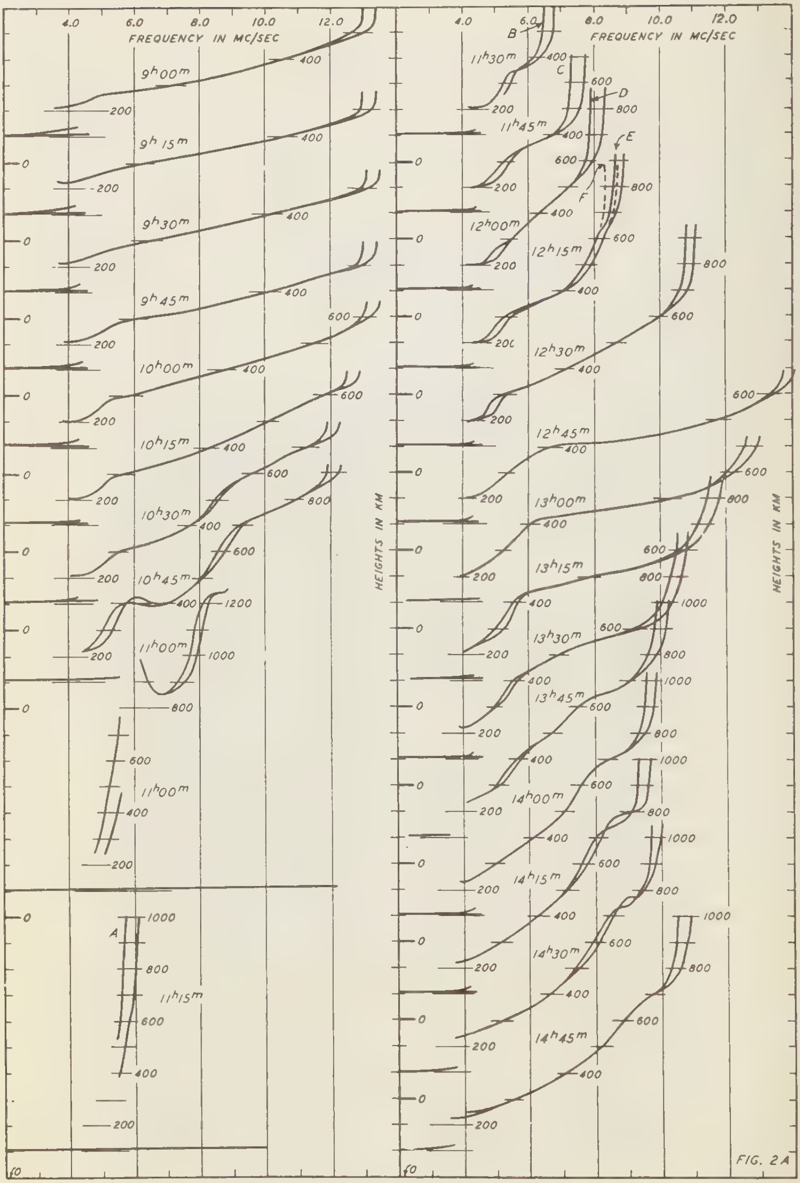


FIG. 2A

are used to illustrate the observations more clearly. In § 3, these observations are discussed. Attention is given to growth of a "new" F_2-layer whose change during the interval can be considered as inde-

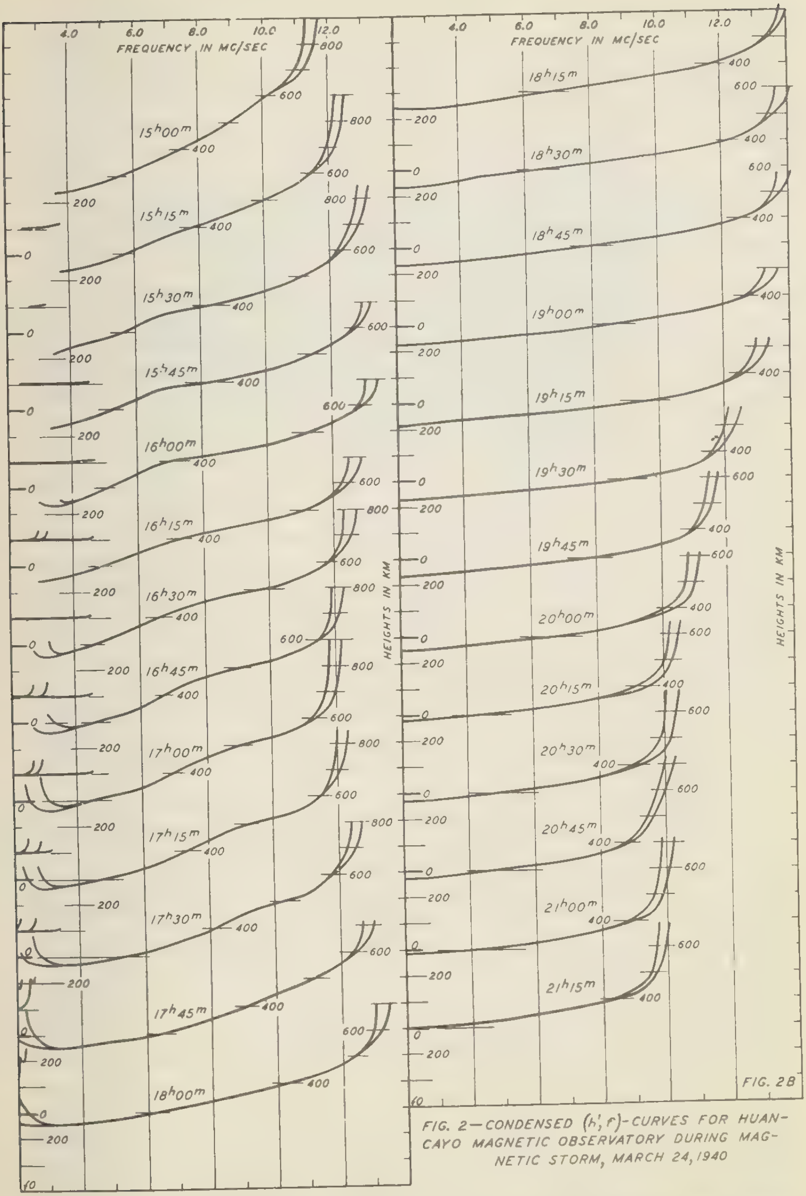


FIG. 2—CONDENSED (h', f)-CURVES FOR HUANCAYO MAGNETIC OBSERVATORY DURING MAGNETIC STORM, MARCH 24, 1940

pendent of zenith-distance of the Sun. Values of recombination-coefficient and ion-production at the level of maximum ion-density are estimated. These are used to compute the abnormal rate of change of ion-

density during the storm. Observations at the Watheroo Magnetic Observatory are presented in § 4 where a number of original records are reproduced to illustrate development of the disturbance. These are discussed in § 5. The evidence indicates large spatial tilts of iso-ionic surfaces near Watheroo about 40 minutes after commencement of the large magnetic changes. In § 6, time-coincidence of ionospheric effects at both observatories is considered. Radio fade-outs and bright solar chromospheric eruptions before and during the storm are shown.

In discussing observations at a particular locality, local standard time is used, that reference to the local day may be retained; otherwise Greenwich mean time (GMT) is used.

Records show the multifrequency trace in terms of frequency and virtual height. Interpretation of these records has been fully discussed by Berkner [4] and by Booker and Seaton [5]. At Watheroo the fixed frequency, 4.8 mc/sec, is recorded near the upper part of the record. This is superimposed upon the high multiple reflections of the multifrequency trace. Time moves from right to left on the records, that is, from higher to lower frequency. When a record is designated by a single time, time of commencement is implied.

§ 2. *Observations at Huancayo Magnetic Observatory* (12° 02.′7 south, 75° 20′.4 west)

No unusual ionospheric characteristics are evident during the moderate geomagnetic activity preceding the violent phase of the storm. Penetration-frequency is about 20 per cent above average, as is normal at Huancayo for moderate geomagnetic activity [6]. At $09^h\ 45^m$ ($14^h\ 45^m$ GMT) the record appears quite normal for moderate geomagnetic disturbance. The first record in which any unusual change can be detected is that at 10^h. Original records from 10^h through $12^h\ 55^m$ are reproduced in Figure 1. In Figure 2, first reflections of all records from 09^h through $21^h\ 15^m$ are represented in condensed form so that successive changes may be easily discerned.

At 10^h, height of the upper part of F_2-layer shows a distinct rise.* The lower part of this layer and lower layers, from which echoes are returned at wave-frequencies below 6.2 mc/sec, remain unchanged. This initial rise precedes by about 40 minutes the first really large geomagnetic movement; it corresponds to quite marked and increasing geomagnetic fluctuations which followed the sudden commencement at $08^h\ 49^m$ (75° west meridian time). The succeeding two records show development of this increase in height, but not until $10^h\ 45^m$ are the lower F_2-layer or the F_1- and E-layers affected. The slight drop of penetration-frequency before this time is quite normal for this time of day. For reference, variations in horizontal intensity of geomagnetism at Huancayo may be found in Figure 13.

The record at $10^h\ 45^m$ marks the commencement of violent disturbance of both magnetic and ionospheric conditions. The changes after $10^h\ 45^m$ seem a continuation of preceding height-changes, but at

*In this paper the terms "region" and "layer" are used in accordance with the recent standard definitions of the Wave-Propagation Committee of the Institute of Radio Engineers. These are as follows:

"*Region*—A region of the ionosphere is a portion of the atmosphere in which there is a tendency for the formation of definite ionized layers."

"*Layer*—A layer of the ionosphere is a regularly stratified distribution of ionization which is formed in a region of the ionosphere and is capable of reflecting radio waves back to Earth."

a more rapid pace. The F_2-layer disappears in two distinct steps. While the whole layer rises quickly, electron-densities above 10^6 (corresponding to reflection above 9 mc/sec) rise more rapidly so that electron-densities between 10^6 and 1.7×10^6 disappear almost simultaneously before 11^h. That portion of the F_2-layer embracing these densities seems to break away from the lower F_2-layer in a continuation of the rise which started at 10^h; its density falls as great heights are reached. Between 11^h and $11^h\,15^m$ the lower F_2-layer rises similarly and ion-density diminishes. By $11^h\,15^m$ no trace of ionization in the F_2-region remains evident. Only echoes from the F_1-layer can be observed. The rise of virtual height of particular electron-densities observed in the F_2-region during this interval is extremely rapid—changes in the neighborhood of 30 km per minute or in excess of the velocity of sound. Just how much of this apparent velocity is attributable to actual change in height of particular electrons, how much to redistribution of densities in less ionized regions, and how much to wave-retardations introduced by redistribution of ionization during these changes, cannot be ascertained exactly. Determination of actual distribution directly from successive records cannot, unfortunately, be made by the method of Booker and Seaton [5] because of rapid change in height with time. Application of the method to values interpolated between records leads to a real change of height of electron-maximum of about eight km per minute or about one-third the velocity of sound (compare with values at Huancayo for geomagnetic disturbance of April 16, 1938 [7]).

While the records of Figure 1 show both strong reflections and weaker boundary-reflections from E-layer, only the principal E-layer echoes are represented in Figure 2. Commencing about $10^h\,45^m$ electron-density of E-layer is about 40 per cent above normal through $11^h\,15^m$. During this time echoes from F_1-layer cannot be seen below five mc/sec; throughout the interval only E-layer echoes are observed on the fixed-frequency record of 4.8 mc/sec.

The first phase of the ionospheric disturbance described above may be characterized by complete disappearance of F_2-layer with exceptionally high E-layer electron-density. The initial enormous rise in horizontal intensity took place between $10^h\,41^m.5$ and $10^h\,45^m$. The fall to a value lower than the original strength occurred during the same interval from $10^h\,45^m$ to about $11^h\,30^m$. F_2-layer was swept out by $11^h\,20^m$ after which there was nothing left in the F_2-region which could be observed.

The second phase of the disturbance, commencing about $11^h\,30^m$, shows the growth of what seems to be an entirely "new" F_2-layer at normal heights. Successive records through $12^h\,15^m$ show a slow but steady increase of F_2-layer ion-density. Appearance of a "double" penetration-frequency at $12^h\,15^m$ (E in Fig. 2) heralds an extremely rapid rise in electron-density. This reached very high values within the next half-hour. The growth of F_2-layer during this phase is discussed in detail in the next section.

Subsequent variations in F_2-layer appear a sort of oscillation of height and ion-density at almost regular three-hour intervals. Each column in Figure 2 involves about three hours of records. The almost regular repetition in procession of heights and penetration-frequencies in each column is quite apparent. This can be better observed by reference to the subsequent Figures.

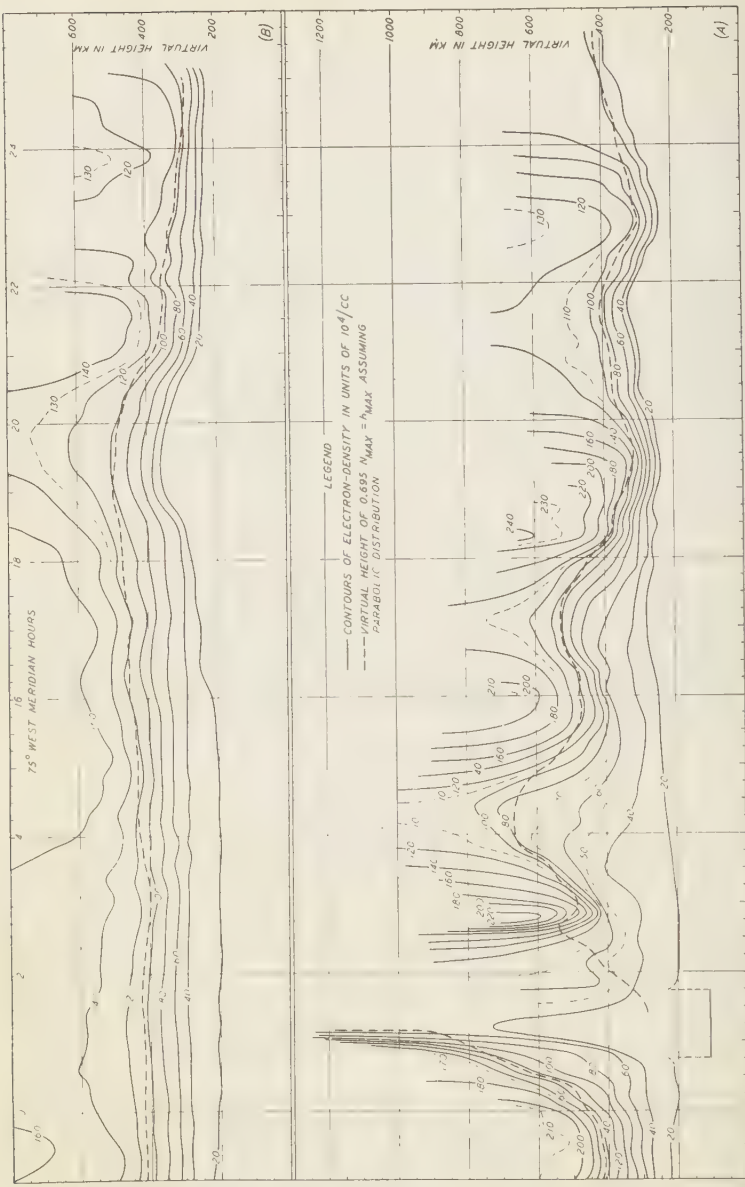


FIG 3—ISO-IONIC GRAPH (h′, t) DEDUCED FROM FIGURES 1 AND 2: (A) ILLUSTRATING VARIATION OF F-REGIONS AT HUANCAYO MAGNETIC OBSERVATORY DURING MAGNETIC STORM OF MARCH 24, 1940, COMPARED WITH (B) NORMAL-DAY VARIATIONS OF MARCH 22, 1940

Figures 3 and 4 form normal cross-sections of a three-dimensional figure involving virtual height, electron-density, and time. They are constructed from the graphs of Figure 2 and similar graphs representing

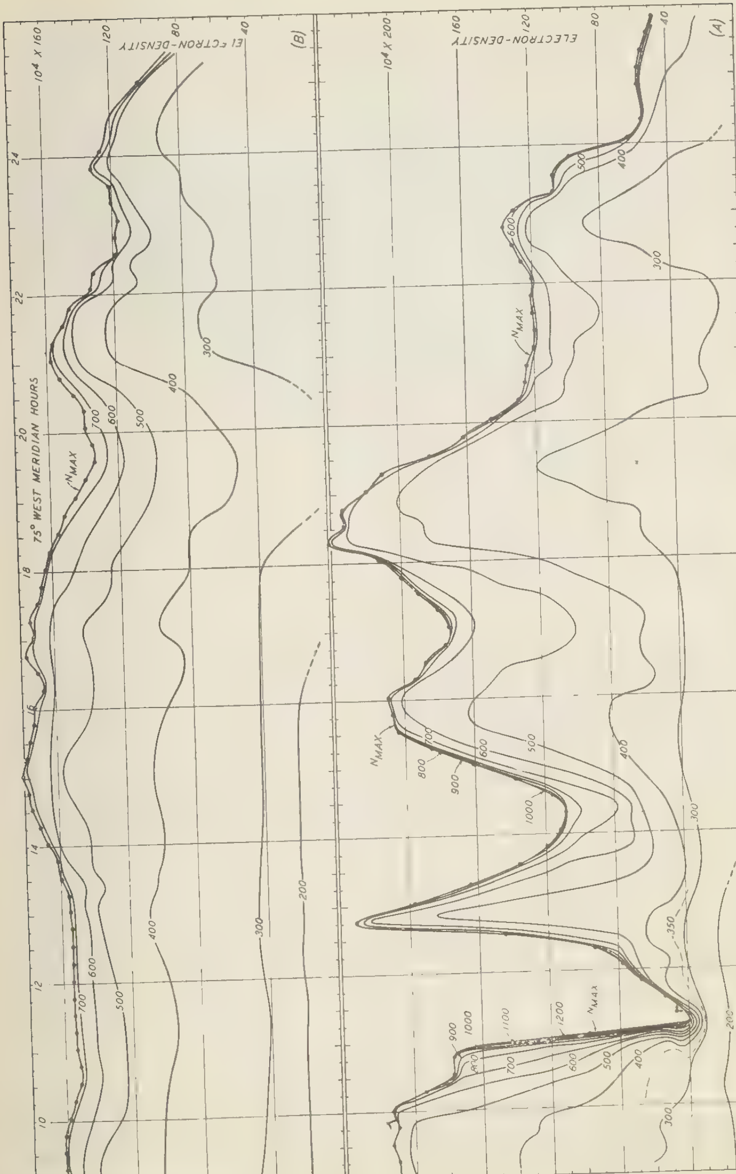


FIG. 4—VIRTUAL HEIGHT CONTOURS (N, t) DEDUCED FROM FIGURES 1 AND 2: (A) ILLUSTRATING VARIATIONS OF F-REGIONS AT HUANCAYO MAGNETIC OBSERVATORY DURING MAGNETIC STORM OF MARCH 24, 1940, COMPARED WITH (B) NORMAL DAY VARIATIONS OF MARCH 22, 1940

conditions during subsequent hours. A graph representing conditions on the relatively quiet day, March 22, 1940, is shown in the upper portion of each Figure to permit ready comparison. These Figures combine

the whole of the ionospheric observations during the storm and provide interpolation between successive records. The succession of events is completely illustrated, except that between $10^h\,45^m$ and $11^h\,15^m$ changes are so drastic as to be impossible of accurate representation on this scale. If the pages are lifted so the Figures are normal to each other, perspective in three dimensions can be obtained. The almost periodic character of the fluctuation of density and height following the initial disturbance of the ionosphere is evident in these Figures. Succeeding maxima and minima of electron-density with corresponding minima and maxima of virtual height are repeated with remarkable regularity (see Table 1). Only the interval at sunset shows a marked difference from the others. At this time, electron-density diminishes very rapidly. Perhaps the next minima and maxima may be shifted for this reason.

Table 1—*Time of successive maxima and minima of electron-density, Huancayo Magnetic Observatory*

Maxima	Minima	Interval
h *m*	*h* *m*	*h* *m*
	11 14	
12 49		1 35
	14 20	1 31
16 01		1 41
	17 16	1 15
18 45		1 29
	21 15	2 30
22 47		1 32

The mean-time difference between minima and maxima is 1 hour 30 minutes, excepting the difference between $18^h\,45^m$ and $21^h\,15^m$. We conclude therefore that after initial disappearance of F_2-layer, the change of maximum ion-densities and virtual heights can be described as a sort of oscillation of diminishing amplitude around the mean with a period of about three hours and duration of three and one-half or four periods.

In concluding this description, it must be emphasized that these are unusual effects at Huancayo. Only twice before, during magnetic storms of great severity on January 22, 1938, and April 16, 1938, has the F-region been swept out at Huancayo—on both previous occasions this occurred at night [7]. In the usual course of events, particularly during daylight, F_2-layer electron-density increases steadily at level of maximum as magnetic activity becomes more intense [6]. Only during the really great magnetic disturbances (which should probably be rated in excess of 2.0 on the international scale of magnetic character-figure) is the F_2-layer "blown out" as observed on this occasion.

§ 3. *Discussion of observations at Huancayo*

The interval immediately following destruction of F_2-layer warrants detailed attention. During this time it appears that a new F_2-layer is produced. This interval centers around noon when the zenith-distance is small and there is little change in incident solar radiation with time. Because the original ion-density has been reduced to a low value, the region may be regarded as an un-ionized atmosphere which is suddenly exposed to uniform solar radiation. It will be shown that growth of ionization

during this interval is practically independent of zenith-distance. Under these conditions it is possible to estimate the effective recombination-coefficient and rate of ion-production at the level of maximum electron-density if it is assumed that the electrons are not moved from the vicinity in which they are produced. This assumption may be properly questioned coming immediately following the extremely rapid disappearance of the F_2-layer. Nevertheless there is evidence that this assumption may be tenable. Furthermore, the opportunity to observe the growth of ionization under conditions essentially independent of other variables is so unusual as to encourage an attempt at such an estimate. The results are illustrated in Figures 5 and 6.

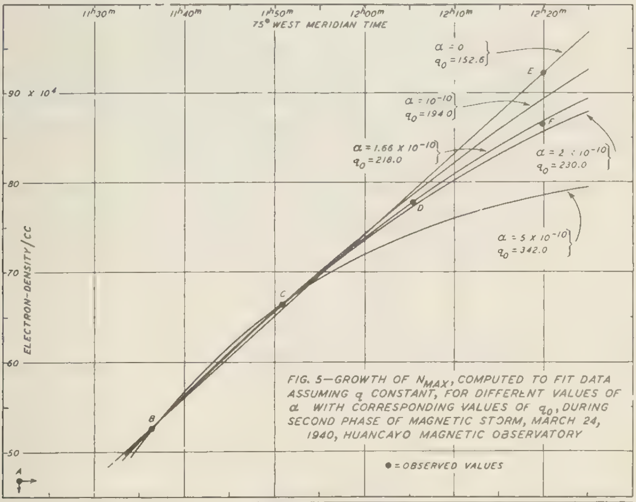


FIG. 5—GROWTH OF N_{MAX}, COMPUTED TO FIT DATA ASSUMING q CONSTANT, FOR DIFFERENT VALUES OF α WITH CORRESPONDING VALUES OF q_0, DURING SECOND PHASE OF MAGNETIC STORM, MARCH 24, 1940, HUANCAYO MAGNETIC OBSERVATORY

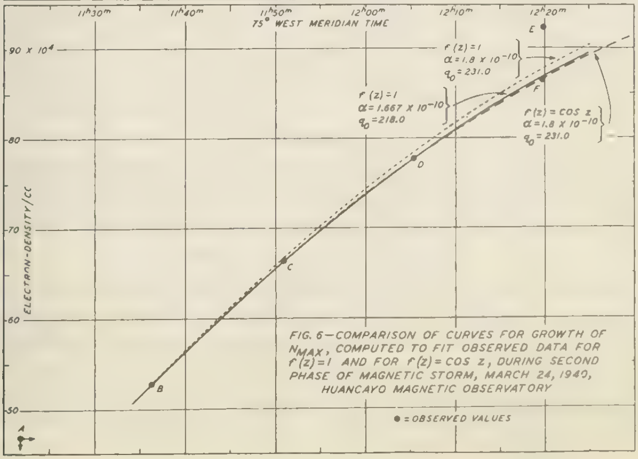


FIG. 6—COMPARISON OF CURVES FOR GROWTH OF N_{MAX}, COMPUTED TO FIT OBSERVED DATA FOR $f(z)=1$ AND FOR $f(z)=\cos z$, DURING SECOND PHASE OF MAGNETIC STORM, MARCH 24, 1940, HUANCAYO MAGNETIC OBSERVATORY

In Figure 5, observed points A, B, C, D, E, and F correspond to penetration-frequencies which are similarly identified in Figure 2-*B*. Point A simply indicates that the electron-density was below that value. Point F is taken from an extrapolation of the lower branch of the "double" penetration-frequencies on the record for $12^{h}\ 15^{m}$ shown in Figure 1-*B* and 2-*A*. Our interpretation of the significance of point E corresponding to the upper branch of the two penetration-frequencies will be mentioned in subsequent discussion. The problem is to fit these points with a curve for growth of ion-density based on appropriately chosen constants.

The curves of Figure 5 are computed with the ion-production q at level of maximum ion-density assumed as a constant over the interval so that $q=q_0$. This is essentially in agreement with the hypothesis of Bradbury [8] and of Mohler [9] that maximum ion-density of the F_2-layer is far above the level of maximum ion-production. According to this view the layer is produced because the effective recombination-coefficient, α, increases with decreasing height. Chapman [10] has shown that ion-production is nearly constant throughout the day at a level which is several units of scale-height above the level of maximum ion-production.

In this case, electron-density, N, will vary according to

$$(\mathrm{d}N/\mathrm{d}t)=q_0-\alpha N^2 \tag{1}$$

The solution for this equation may be written as

$$N=N_0(\exp 2\sigma_0 t-1)/(\exp 2\sigma_0 t+1) \tag{2}$$

where $N_0=\sqrt{q_0/\alpha}$ is the equilibrium-ionization reached after an indefinitely long interval, and $\sigma_0=\sqrt{q_0\alpha}$ determines the time required to reach a particular fraction of equilibrium-ionization.

The points B, C, D, and F of Figure 5 can be fitted closely for values of

$$\left.\begin{aligned}\alpha&=1.66\times10^{-10}\\ q_0&=218\end{aligned}\right\} \tag{3}$$

assumed for the level of maximum electron-density. These correspond to equilibrium-ionization, $N_0=1.15\times10^{6}$ electrons/cc, and $\sigma_0=1.9\times10^{-4}$ so that at a time $(2/\sigma_0)=2.92$ hours, 96.4 per cent of equilibrium-ionization is reached.

To demonstrate that variation of zenith-distance has little effect on the result, an additional curve has been computed in Figure 6, assuming

$$q=q_0\cos z$$

where z is the zenith-distance. This is the form of variation realized when the level of maximum ion-density is at the level of maximum ion-production as shown by Chapman [10] and by Hulburt [11]. Then (1) becomes

$$(\mathrm{d}N/\mathrm{d}t)=q_0 f(z)-\alpha N^2 \tag{4}$$

This equation can be solved numerically by a step-by-step method. Take any short interval, Δt, over which $\cos z$ can be considered to vary linearly to a sufficient degree of approximation. Let the zenith-distances at the limits of the interval be z_1 and z_2. Then the average ion-production per second over the interval will be

$$(q_1+q_2)/2=q_0(\cos z_1+\cos z_2)/2=q_0 f(z) \tag{5}$$

Similarly the average loss per second over the interval will be

$$(L_1+L_2)/2=\alpha(N_1^2+N_2^2)/2$$

If $\triangle N$ is the change of ion-density over the interval, $\triangle t$, then $N_2=N_1+\triangle N$, so that

$$\overline{L}=\alpha(N_1^2+N_1^2+2\triangle N\ N_1+\triangle N^2)/2$$

If the time-interval is not too long, $(\triangle N^2/2)$ can be neglected so that

$$\overline{L}=\alpha N_1 N_2$$

and from (4)

$$N_2-N_1=q_0\triangle t f(z)-\alpha\triangle t N_1 N_2$$

from which

$$N_2=[N_1+q_0\triangle t f(z)]/[1+\alpha N_1\triangle t] \qquad (6)$$

Successive values of N can be computed step-by-step from (6) with values of $f(z)$ computed from (5). Intervals of ten minutes give sufficient accuracy for most purposes yielding three significant decimal places except very near sunrise and sunset. The equation is of such form that when computed in the direction of advancing time, errors caused by curvature over the selected interval rapidly disappear when α is less than 10^{-7}, and are not continuously cumulative. The curve computed to fit the observed data by this method yields the values

$$\left.\begin{array}{l}\alpha=1.8\times10^{-10}\\ q_0=231\end{array}\right\} \qquad (7)$$

The curve from (5) and (7) is compared to that from (2) and (3) in Figure 6 where the two scarcely differ. Similarly the values deduced by the two methods differ but little. We conclude therefore that within the limits of the assumptions, the values of q_0 and α deduced from these data for the level of maximum ion-density are practically independent of z.

In these computations we have assumed implicitly that the level of maximum ion-density remained constant during growth of the region. That this is not the case is evident from Figure 3 where the level of maximum electron-density, represented by the heavy dashed line, rises almost linearly from 300 to 460 km between points B and F. This rise can be explained in two ways. First, there may be a physical rise in the region of the same nature, but less violent than that experienced during the destruction of the F_2-layer. This would in some measure vitiate the validity of the assumption made in the foregoing computations. Second, the rise can occur if q and α vary with respect to height in such a way that q increases less rapidly than α toward lower levels. Computations based on the latter hypothesis lead to somewhat larger values of q and α than those given above and produce the observed height-changes without movement of ions from the vicinity in which they are produced. An account of this work will be given in a later paper.

The disappearance and subsequent reappearance of F_2-layer during the interval $10^h\,45^m$ to 14^h can now be examined quantitatively. In Figure 7, the heavy line through the observed points represents the change in maximum ion-density over the interval referred to the left-hand

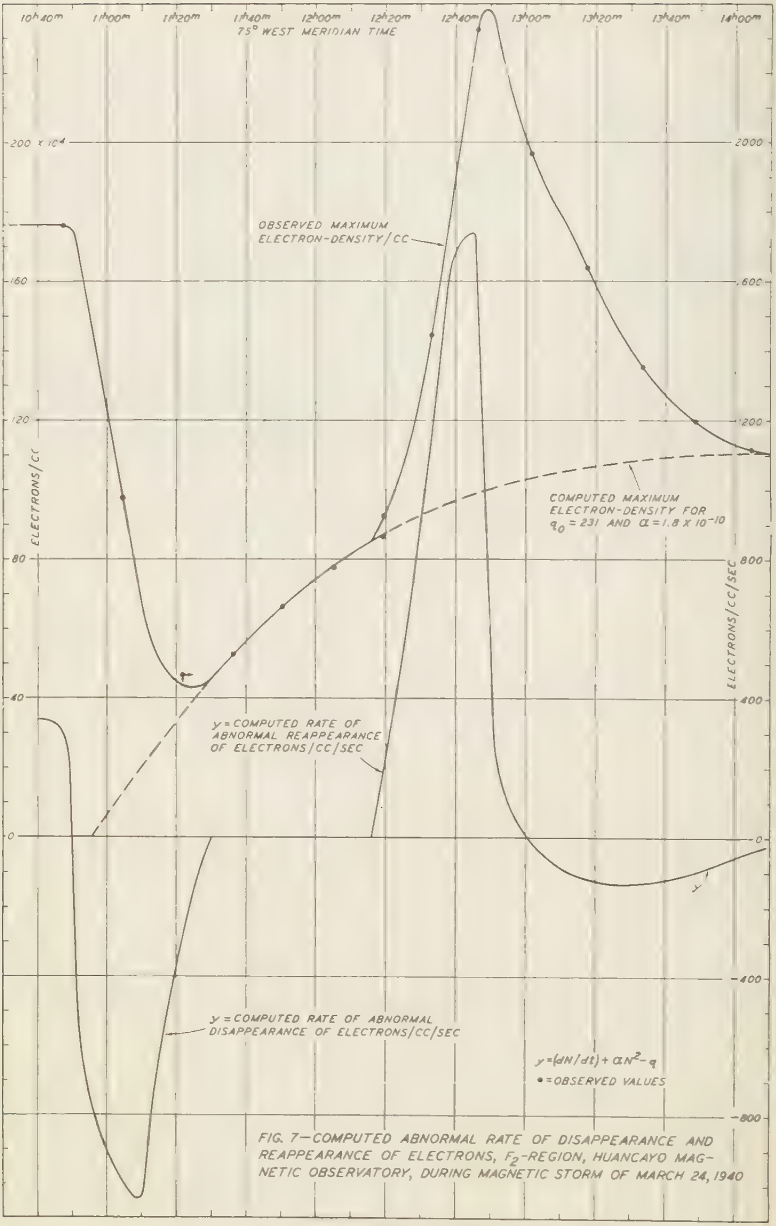


FIG. 7—COMPUTED ABNORMAL RATE OF DISAPPEARANCE AND REAPPEARANCE OF ELECTRONS, F_2-REGION, HUANCAYO MAGNETIC OBSERVATORY, DURING MAGNETIC STORM OF MARCH 24, 1940

ordinate-scale of the Figure. The six observed points between $11^h\, 20^m$ and $12^h\, 20^m$ are the points A, B, C, D, E, and F identified with Figures 5 and 6.

We assume from the previous discussion that the ordinary production of F_2-layer over the interval can be described satisfactorily with values of $\alpha = 1.8 \times 10^{-10}$ and $q_0 = 231$. The rate of abnormal change of ionization, y, can be expressed by

$$y = (\mathrm{d}N/\mathrm{d}t) + \alpha N^2 - q \tag{8}$$

or in the approximate form of (6) for purpose of computation

$$y = [(N_2 - N_1)/\triangle t] + \alpha N_1 N_2 - q_0 f(z) \tag{9}$$

Abnormal rate of change of ion-density at the level of maximum for the data of Figure 7 has been calculated in this way and plotted in terms of the right-hand ordinate-scale. According to this argument the F_2-layer is initially swept out at an abnormal rate which reaches a maximum of about 1000 electrons/cc/sec at about $11^h\, 15^m$. The computed abnormal decrease takes place between $10^h\, 45^m$ and $11^h\, 30^m$. This interval corresponds almost exactly to the rapid fall in horizontal intensity which followed the initial rise at Huancayo at the ground and averaged some 25 gammas per minute (see Fig. 13). During the interval of abnormal disappearance the heights were changing rapidly upward. This leads to a suggestion that the electrons were physically transported upward into more tenuous regions so that the observed maximum was reduced by expansion. Identification, in time, of the magnetic change mentioned above, with this upward transport leads one to suppose that the effects may be quite directly related. We may well ask to what extent could changes of geomagnetic field account for the observed transport of electrons? Or, on the other hand, could the observed changes of field have been produced, at least in part, by the violent changes in the layer?

Next occurs a period with no abnormal change, a condition arbitrarily introduced by the assumptions. At $12^h\, 15^m$ an interval of abnormal rate of reappearance of electrons begins, with the rate rising to about 1700 electrons/cc/sec at $12^h\, 45^m$—just 1.5 hours after the maximum of abnormal disappearance. Subsequent values of y are very small in comparison with these maxima.

In noting the abnormal rates given above it must be remembered that these are computed at the level of maximum electron-density. Large spatial redistribution of ionization appears to be taking place while abnormal production or inflow is also taking place. The values computed must therefore be in considerable error as indicators of the actual rate of abnormal production or inflow in a particular unit-volume. They give only the lower limit of the net gain or loss at the continually changing level of maximum density.

During the interval of abnormal reappearance, the heights were falling rapidly. This leads to a suggestion that electrons were transported down into the F_2-region at a rate such that the process took complete control of the distribution-curves. If this view is correct, point E of Figures 2, 5, and 6, representing the upper branch of the double penetration-frequency in Figure 2, has unique significance. The lower

penetration-frequency, F, represents the maximum density of the region produced by normal processes. The hump between E and F is the first appearance, just at the level of maximum ion-density, of the downcoming abnormal ionization, which pushes the final penetration-frequency to point F. Continued inflow of downward moving ionization during the succeeding interval then takes control of the distribution, twisting the height-curves downward and toward higher frequencies as is evident in Figure 2 ($12^h\,15^m$ to $12^h\,45^m$). This evidence appears to strengthen the validity of the assumptions made in computation of q_0 and α to the extent that the time of abnormal reappearance of ionization seems definitely marked on the records.

Subsequent oscillations of ion-density and height may be a repetition of these same phenomena, but on a much smaller and diminishing scale. The general pattern of change of ion-distribution is repeated during each fluctuation.

§ 4. *Observations at Watheroo Magnetic Observatory* (30° 19′.1 south, 115° 52′.6 east)

At Huancayo the disturbance occurred near noon and at Watheroo it began at midnight. We are interested primarily in making a time-comparison of various corresponding events at the two observatories to determine the extent to which they may be simultaneous in both daylight and dark hemispheres. Development of the disturbance at Watheroo is graphically shown in the records of Figures 8 and 9. In Figure 10 maximum ion-densities and minimum virtual heights are abstracted from the records. A mark will be noted at the lower left-hand corner of each record, just above the base-line between 0.5 and 1.0 mc/sec; this is not an echo, but is introduced by proximity of output-frequency to intermediate-frequency of the equipment. It is therefore without significance.

This ionospheric disturbance follows the general pattern of nearly all severe ionospheric disturbances at Watheroo. At night such disturbances are characterized by increased scattering of echoes until in extreme cases distinct penetration-frequencies can no longer be discerned. A pronounced reduction in electron-density for F- or F_2-layer accompanies moderate to severe magnetic disturbances. Normally smooth, stratification of the ionosphere is broken leaving clouds of varying density and size. Scattering is predominant in F-region, extending to E-region during more intense disturbance. These effects are the same as those observed at the Kensington (Maryland, United States of America) Experimental Station in latitude 39° 01′ north and longitude 75° 04′ west, described in detail in an earlier publication in this Journal [7]. In fact, nearly all effects associated with magnetic activity in the two localities appear essentially similar during corresponding seasons. We can therefore generalize the earlier detailed description at Kensington to include both north and south temperate zones.

There are certain features of the ionospheric disturbance at Watheroo which are worthy of particular attention. The ionosphere above Watheroo is relatively undisturbed through $22^h\,45^m$ (corresponding to $09^h\,15^m$ at Huancayo). Not only are penetration-frequencies for F_2-region identical at 22^h on the 22d and 24th, but shape of the

(h', f)-curves is very similar. This can be inferred readily by comparison of corresponding high-order multiple echoes. Just before 23^h the height starts to rise slowly above normal so that at $23^h\,42^m$ the height is about 15 per cent above its usual value. This rise agrees almost exactly in time

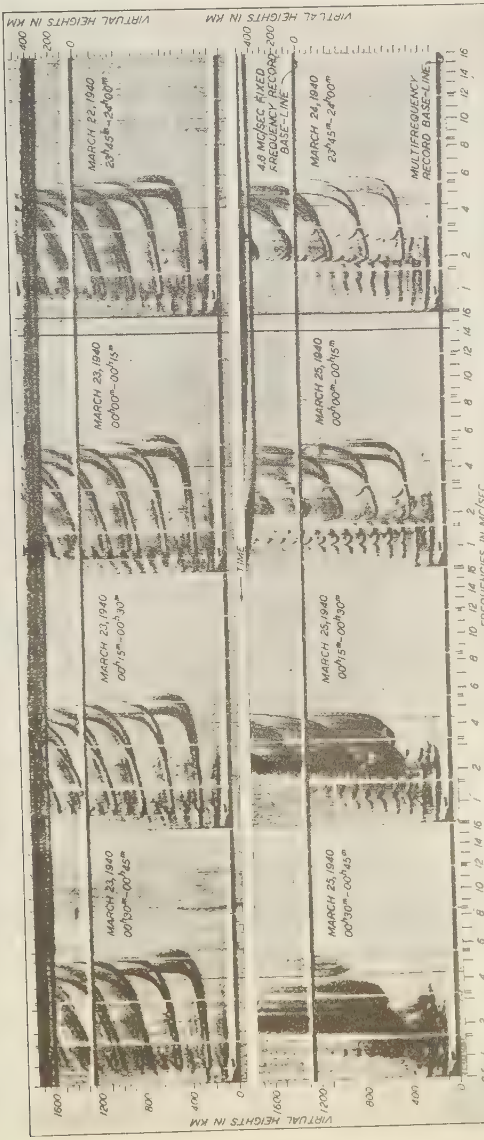
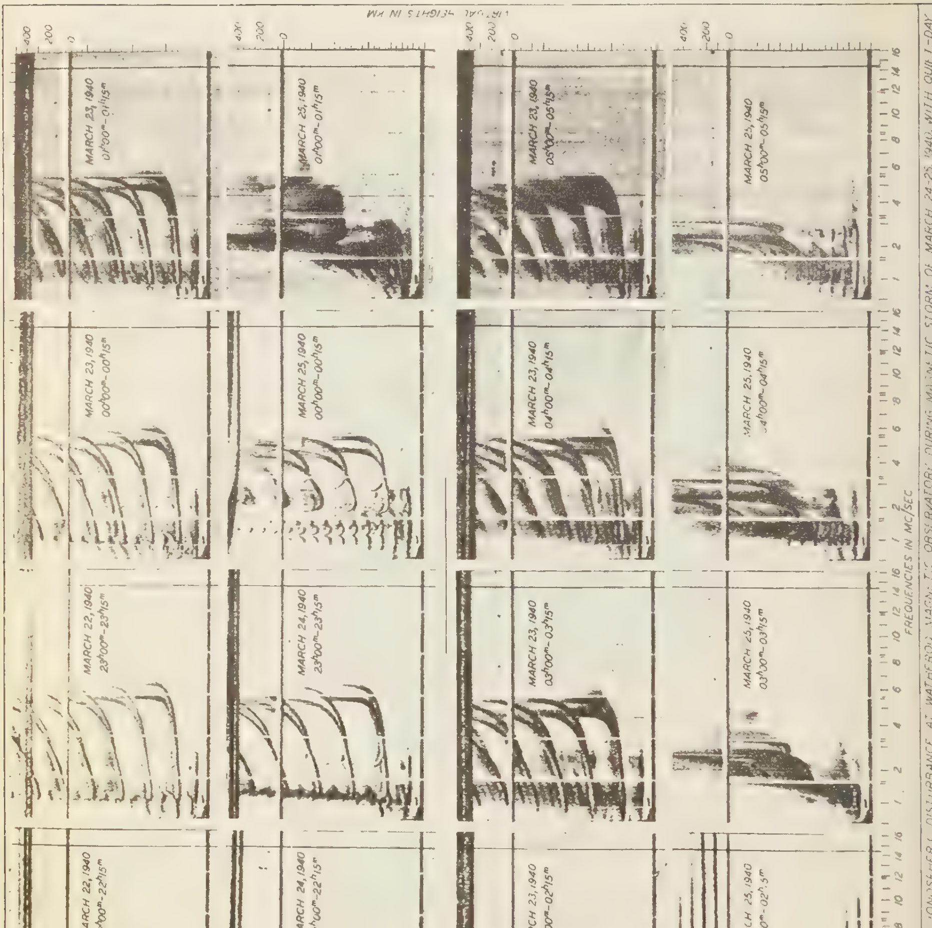


FIG. 8—RECORDS ILLUSTRATING COMMENCEMENT OF IONOSPHERIC DISTURBANCE AT WATHEROO MAGNETIC OBSERVATORY COINCIDENT WITH MAGNETIC STORM OF MARCH 24-25, 1940, COMPARED TO QUIET CONDITIONS OF MARCH 22-23, 1940



with the slow change of upper F_2-region at Huancayo preceding the first violent geomagnetic change.

Commencing at $23^h\,42^m$ (that is, coinciding with the first large magnetic movement at $15^h\,42^m$ GMT) the height falls slightly until about

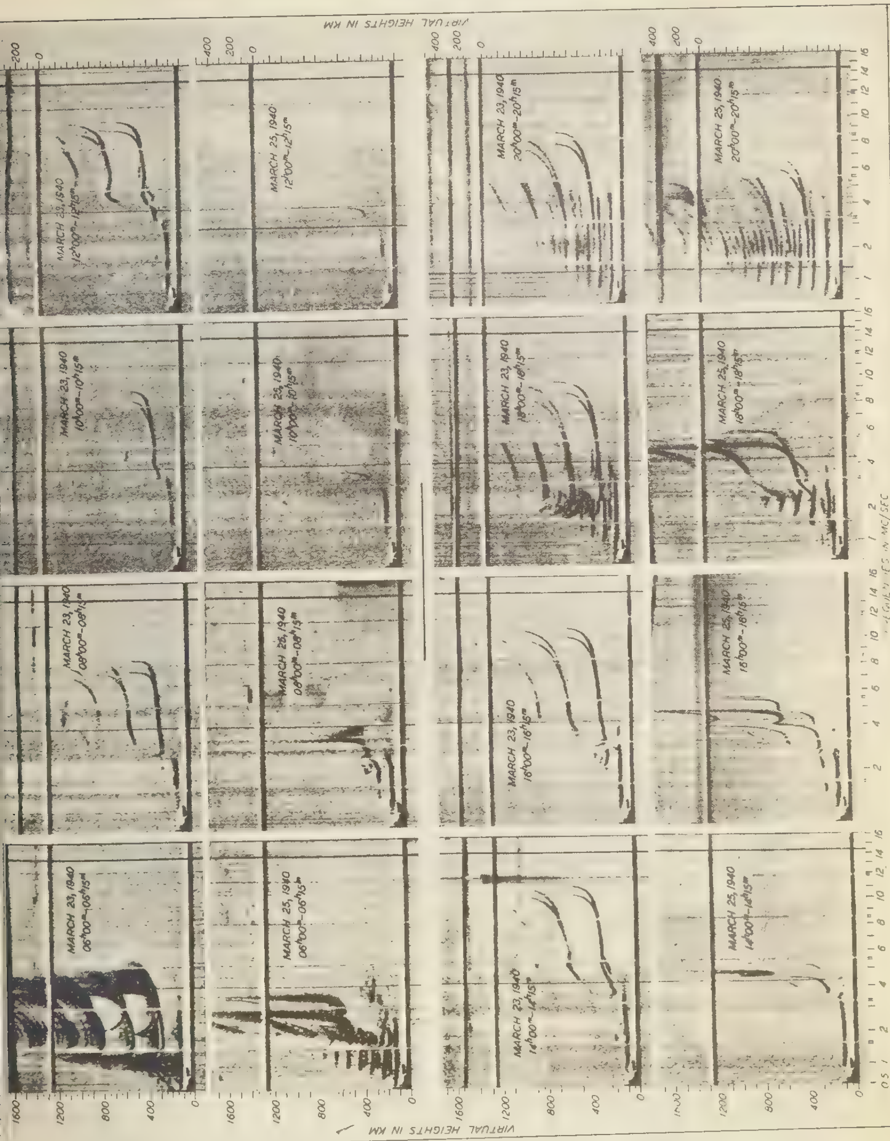


FIG. 9B—RECORDS COMPARING IONOSPHERIC DISTURBANCE AT WATHEROO MAGNETIC OBSERVATORY DURING MAGNETIC STORM OF MARCH 24 25, 1940, WITH QUIET-DAY CONDITIONS OF MARCH 22-23, 1940

00^h when it moves rapidly upward. As nearly as can be determined from both fixed and multifrequency traces, the penetration-frequency starts to fall at $23^h\,59^m$. The unusual character of the fixed-frequency trace at this time is discussed in the next section. Following these initial changes,

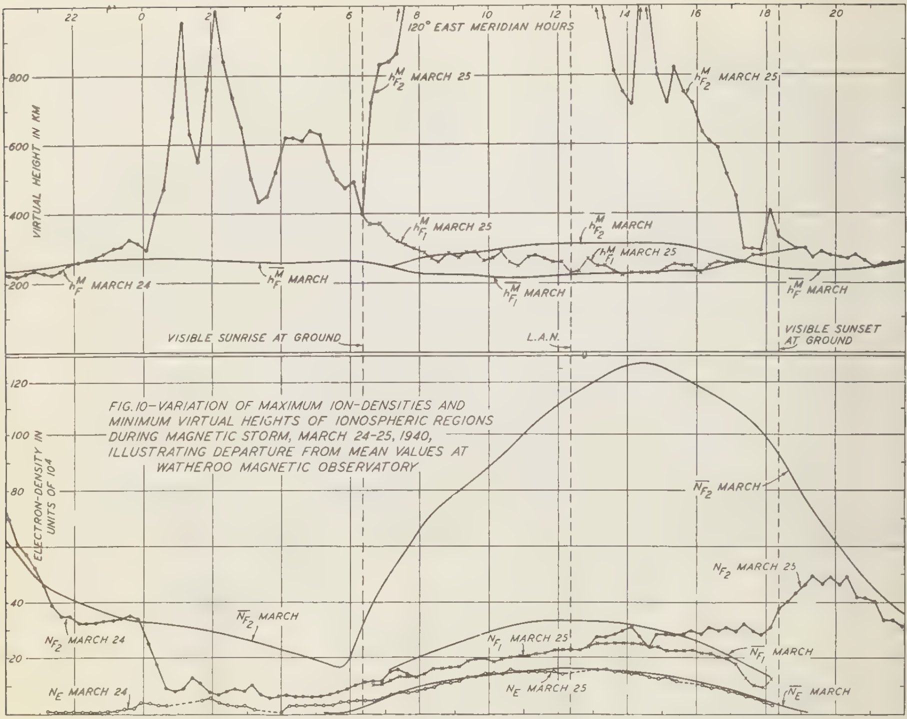


FIG. 10—VARIATION OF MAXIMUM ION-DENSITIES AND MINIMUM VIRTUAL HEIGHTS OF IONOSPHERIC REGIONS DURING MAGNETIC STORM, MARCH 24-25, 1940, ILLUSTRATING DEPARTURE FROM MEAN VALUES AT WATHEROO MAGNETIC OBSERVATORY

height of *F*-layer rises rapidly, electron-density drops far below normal, and scattering becomes predominant. The rapidity with which these ionospheric changes take place is illustrated in Figure 8.

E-layer electron-density is normally very low at night. At $23^h\,45^m$, coinciding with the first large magnetic movement, *E*-layer density jumps suddenly to values far above normal remaining high, though fluctuating, throughout the night.

At times, reflection-coefficients for *E*-layer are extremely high; for example, at $00^h\,13^m$, fourteen multiple echoes are observed. At 02^h strong sporadic *E*-layer echoes appear superposed upon a second system of echoes from *E*- and *F*-regions. To produce such superposition, echoes must be coming simultaneously from different nearby areas of the ionosphere which have quite different structures. This indicates the extremely cloudy, patchy condition which must exist at this time. (Contrast this condition with that at Huancayo where echoes remained clear-cut, without scattering, at all times.)

The disturbance is especially marked during subsequent daylight hours on March 25. F_2-layer appears for a short time with slightly greater ion-density than F_1-layer. Then as F_1-layer grows in ion-density with the rising Sun, F_2-layer disappears behind it and remains unseen until after noon. Then it starts a slow rise toward normal density which

is reached in the evening. F_1-layer rises to only about 75 per cent of its normal ion-density during the day, while density of E-layer appears quite normal. Recovery to generally normal conditions is reached in the neighborhood of 19^h which corresponds to the ending of severe geomagnetic disturbance (11^h GMT).

§ 5. *Discussion of observations at the Watheroo Magnetic Observatory*

Coincident with beginning of great magnetic activity, F-layer drops somewhat in height for a few minutes. This is evident on the fixed-frequency trace of Figure 8. Close examination of the trace reveals the following details. The o wave-component drops in height during the interval $23^h 45^m$ to $00^h 01^m$, rising thereafter. The x-component also drops during this interval, but continues to drop until $00^h 07^m$, falling some five or six km during the six minutes after the o-component has started to rise. Two important ways in which this effect may have been produced are considered.

The o wave-component, propagated at wave-frequency 4.8 mc/sec, is reflected at density $N_o = 28.6 \times 10^4$ electrons per cc. The x wave-component, propagated in this case at the same wave-frequency, is reflected at a lesser electron-density. This density is fixed by the strength of the magnetic field at the level of reflection and is expressed [12, 13] by

$$N_x = 1.24 \times 10^4 f(f - f_H) \qquad (10)$$

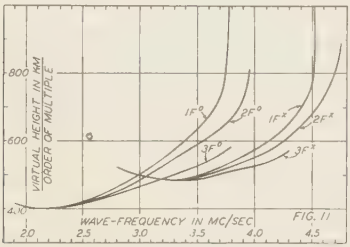
The quantity f_H is $(He/2\pi mc)$ where H is the magnetic field-strength. If f_H is taken as 1.4 mc/sec, echoes of x wave-component are returned at density $N_x = 20.5 \times 10^4$, a value about 25 per cent lower than that required for return of echoes of o wave-component. The difference in movement of o and x wave-components may therefore be explained in the following ways.

First, lower electron-densities in the neighborhood of 20×10^4 per cc, may continue their downward movement after higher densities near 28×10^4 start moving upward. This appears a rather unusual relative movement for two densities not far separated in level in the same layer (less than 25 km). Owing to the steep magnetic inclination at Watheroo, characteristically polarized wave-packets propagated upward are not reflected directly overhead [14, 15]. The o wave-component skids northward toward the equator while the x wave-component is reflected at a point nearer the south magnetic pole. Under this interpretation, the evidence indicates an upward movement of the ionosphere originating to the north of the Observatory and progressing spatially southward with time. Thus the o wave-component experiences the rise in height at the earlier time.

A second explanation depends upon changes of magnetic field-strength. An increase of magnetic field-strength during the interval could cause the virtual height of x wave-component to diminish. This comes about through increase in gyro-frequency f_H, which in turn reduces the electron-density required for reflection and, consequently, the level at reflection. We have calculated the change of virtual height to be expected, assuming parabolic distribution and taking into account variation of magnetic field-strength with height. An increase of two per cent in field will produce a reduction in height of as much as two km under conditions repre-

sented by the records. This amounts to an increase of about 1000 gammas in the magnetic field. In absence of further data, we are inclined to believe that this view must be overstrained to alone produce the effects observed. These two possible effects cannot be separately distinguished in the records. However, the observations suggest allied methods of accomplishing this result which may lead to experiments providing a decisive estimate of the magnetic field-changes in the ionosphere during magnetic storms.

The record for $00^h\ 15^m$ of Figure 8 contains an unusual effect, illustrated in detail in Figure 11. Successive primary echoes between the ionosphere and the Earth do not appear in the usual exact multiple relation. The echoes travel over successively shorter paths for each round trip and penetration-frequency for the $2F$-"multiple" is higher than that for $1F$.



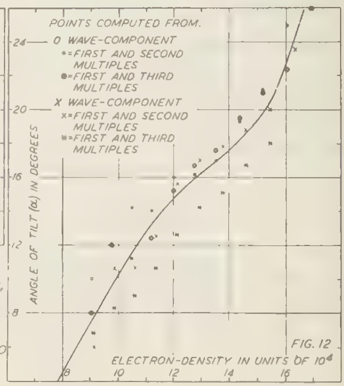


FIG. 11—F-REGION VIRTUAL HEIGHTS DETERMINED FROM SUCCESSIVE MULTIPLES, $00^h 25^m$, 120° EAST MERIDIAN TIME, WATHEROO MAGNETIC OBSERVATORY, MARCH 25, 1940

FIG 12—ANGLE OF TILT OF ISO-IONIC SURFACES COMPUTED FROM SUCCESSIVE MULTIPLES ASSUMING FLAT EARTH AND PLANE ISO-IONIC SURFACES, $00^h 25^m$, 120° EAST MERIDIAN TIME, WATHEROO MAGNETIC OBSERVATORY, MARCH 25, 1940

This effect can be explained if the ionosphere is tilted in space overhead so that successive iso-ionic surfaces are not parallel to the Earth, and probably not parallel to one another. The first echo returning to the receiver is reflected where the wave-normal and the gradient-vector coincide at the appropriate ion-density in the ionosphere. The second multiple echo must be incident normal to the Earth at the midpoint of its path, at a point away from the station. The third multiple is normal to the appropriate iso-ionic surface at the midpoint of its path. Each successive multiple departs at a lower angle of departure. The angle of tilt of iso-ionic surfaces has been calculated from pairs of multiples and is illustrated in Figure 12. This assumes plane, though not parallel, iso-ionic surfaces over an appropriate area. The values must be those for maximum tilt. The azimuth from the station of maximum tilt cannot be ascertained from these data. Calculations using a curved Earth, and iso-ionic surfaces rising as $R \cos \theta$ from an arbitrary reference-point lead to substantially the same angles of tilt. In both cases, the Breit-Tuve equivalence-theorem may be applied. While the exact angle of tilt depends upon the spatial distribution assumed, it will, in any case, be of the general form indicated. The appearance of this marked tilt accom-

panies first indication of rapid rise of height and just precedes serious scattering. In subsequent records scattering is so severe as to prevent measurements of multiple echoes in this way.

§ 6. *General discussion*

Time-coincidence of ionospheric changes at the two observatories is now considered. As closely as can be determined, the maximum ion-density at both observatories started to fall at the same time. This is illustrated in Figure 13 where ratios of observed to monthly mean values are compared. Time at which ion-density started to diminish at Watheroo can be determined most accurately and is very nearly $15^h\ 59^m$ GMT. This is 15 minutes after the first large magnetic movement. The exact

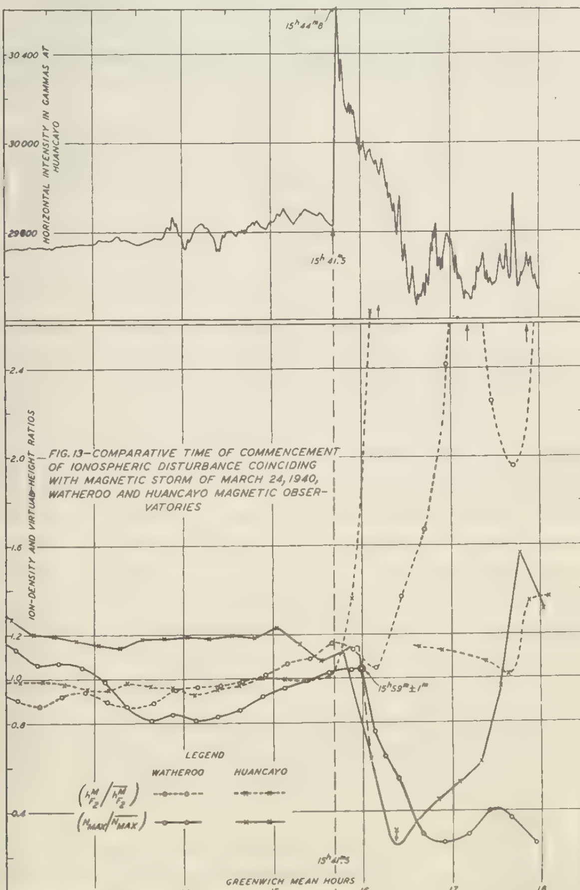


FIG. 13—COMPARATIVE TIME OF COMMENCEMENT OF IONOSPHERIC DISTURBANCE COINCIDING WITH MAGNETIC STORM OF MARCH 24, 1940, WATHEROO AND HUANCAYO MAGNETIC OBSERVATORIES

time at which ion-density began to fall at Huancayo is not so well known, but lies between $15^h\ 50^m$ and $16^h\ 00^m$ which may be anywhere between coincident and nine minutes before Watheroo.

Height-changes show no such agreement. While heights show some abnormal fluctuation before the main magnetic disturbance as described earlier, minimum virtual height of F_2-layer at Huancayo moves up sharply at almost exactly the time of the first major magnetic movement. This is not the case at Watheroo where the sharp upward rise follows between 30 and 40 minutes later. This time-difference appears significant. While at Watheroo the sharp rise in height lagged behind that at Huancayo, it was preceded by the two significant bits of evidence described in section 5. The first is from the fixed-frequency record which indicated a spatial movement in rise of height from north to south. The second is the more positive evidence of spatial tilts of the iso-ionic surfaces which immediately followed. Then, finally, the heights rose sharply.

On two other occasions, accompanying the other two great magnetic storms of recent years, violent upward movement and disappearance of the F-region at Huancayo was observed [7]. On both occasions the effect occurred at night. If Huancayo is representative of the equatorial belt generally, it may be presumed that a similar movement takes place everywhere near the equator at the time of beginning of great magnetic changes. Therefore, it seems probable that such a movement took place in the equatorial belt to the northward of Watheroo as well as at Huancayo. The sequence of events strongly suggests that the spatial movement from north to south, observed at Watheroo, is directly related to the initial upward movement in the equatorial belt. (A station observing at a higher latitude would be extremely helpful in following such changes.)

It will be recalled that during the great magnetic storm of April 16, 1938, violent movements in the F_2-region at Huancayo were accompanied by appearance of an absorbing layer in the neighborhood of 85 km. No such absorbing layer was in evidence at either observatory during the disturbance of March 24, 1940. Only upward extension of the lower absorption-limit, associated with what appear to be normal radio fade-outs, is apparent. This difference may be ascribed to the difference in time of day at which disturbance was incident at Huancayo (where the disturbance of April 16, 1938, occurred at night). During more than two years of observation at Watheroo, no strong absorption-layer associated with magnetic activity has been observed.

Because of interest in the nature of solar activity preceding great magnetic disturbances, solar and radio fade-out observations preceding and during the disturbance are shown in Figure 14 [16]. The minimum absorption-limit on echo return over the interval is compared to the monthly mean values of this quantity [17, 18]. Available solar observations are indicated in the upper portion of the Figure. The fortunate relative locations of Watheroo and Huancayo magnetic observatories where an almost continuous radio watch is maintained on the Sun, is well illustrated in this Figure. During the interval seven fade-outs were observed, marked A to G, respectively. Of these, three were observed to coincide with bright solar chromospheric eruptions. Fade-outs A, E, F, and G appear relatively unimportant. Fade-out B should be particularly noted; it may have been one of the most intense yet observed.

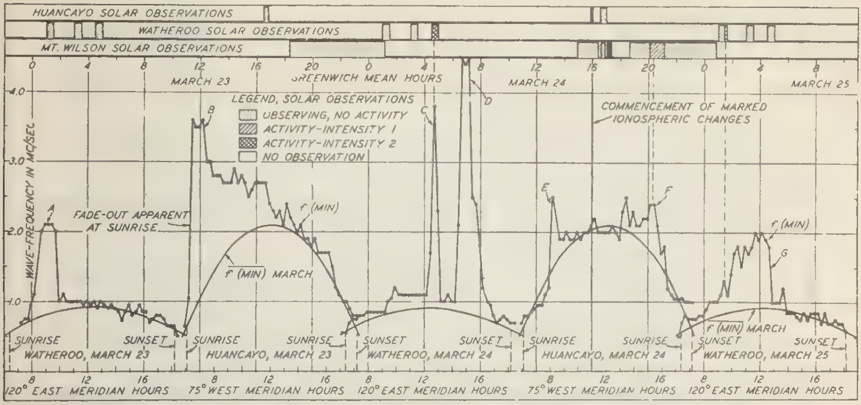


FIG. 14—CHRONOLOGY OF LOWER ABSORPTION-LIMIT RECORDED AT HUANCAYO AND WATHEROO MAGNETIC OBSERVATORIES ILLUSTRATING RADIO FADE-OUTS PRECEDING AND DURING MAGNETIC STORM OF MARCH 24, 1940

As the Sun rose at Huancayo, the minimum absorption-limit immediately rose to abnormal values, reaching 3.6 mc/sec with the Sun's rays at scarcely more than grazing incidence. No effect is observed a half-hour earlier, before sunset at Watheroo, so that the chromospheric eruption responsible for the effect probably started between $10^h\,30^m$ and 11^h GMT. This is the first instance in which we have observed a fade-out coincident with sunrise. The bright eruption producing this effect must have been especially intense. This fade-out preceded the beginning of the major magnetic activity by about 28 hours

While evidence of bright chromospheric eruptions is absent during some of these fade-outs we hesitate to ascribe them to any other cause in the absence of further information. Dr. R. S. Richardson of Mount Wilson Observatory has expressed the opinion that small radio fade-outs may often be accompanied by bright chromospheric eruptions of intensity less than one and that it would be decidedly worth while to record such eruptions

§ 7. *Acknowledgments*

We wish to express to Dr. J. A. Fleming our appreciation for the opportunity to conduct this investigation and for his aid in preparing the material for publication. We are greatly indebted to the members of staff at Huancayo—H. W. Wells, Observer-in-Charge—and at Watheroo—W. C. Parkinson, Observer-in-Charge—for the excellence of the records to which we have referred. It must be a source of satisfaction to all concerned, and a tribute to the care with which observations are made at these observatories, that the ionospheric records are complete in every detail during the disturbed interval. The data on bright chromospheric eruptions observed at Mount Wilson Observatory were kindly supplied by Dr. R. S. Richardson.

References

[1] Principal magnetic storms, Terr. Mag., **45**, 226-234 (1940). See also "Notes," *ibidem*, 235-236.

[2] A. G. McNish, Terr. Mag., **45**, 359-364 (1940).
[3] L. V. Berkner, H. W. Wells, and S. L. Seaton, Trans. Edinburgh Meeting 1936, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, 340-357 (1937); See also Physics of the Earth—VIII. Terrestrial magnetism and electricity (edited by J. A. Fleming), New York, McGraw-Hill Book Co., 434-491 (1939).
[4] L. V. Berkner, Trans. Washington Meeting, 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 417-437 (1940).
[5] H. G. Booker and S. L. Seaton, Phys. Rev., **57**, 87-94 (1940).
[6] L. V. Berkner and S. L. Seaton, Terr. Mag., **45**, 419-423 (1940).
[7] L. V. Berkner, H. W. Wells, and S. L. Seaton, Terr. Mag., **44**, 283-311 (1939).
[8] N. E. Bradbury, Terr. Mag., **43**, 55-66 (1938).
[9] F. L. Mohler, J. Res. Bur. Stan. (in press).
[10] S. Chapman, Proc. Phys. Soc., **43**, 26-45 (1931).
[11] E. O. Hulburt, Phys. Rev., **55**, 639-645 (1939); See also Chapt. X under [3] in second reference.
[12] E. V. Appleton and G. Builder, Proc. Phys. Soc., **45**, 208-220 (1933).
[13] L. V. Berkner and H. W. Wells, Proc. Inst. Radio Eng., **22**, 1102-1123 (1934).
[14] H. G. Booker, Phil. Trans. R. Soc., A, **237**, 411-451 (1938).
[15] H. G. Booker and L. V. Berkner, Terr. Mag., **43**, 427-450 (1938).
[16] J. Bartels, N. H. Heck, and H. F. Johnston, Terr. Mag., **44**, 411-454 (1939).
[17] L. V. Berkner and H. W. Wells, Terr. Mag., **42**, 301-309 (1937).
[18] L. V. Berkner, Phys. Rev., **55**, 536-544 (1939).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

SYSTEMATIC IONOSPHERIC CHANGES ASSOCIATED WITH GEOMAGNETIC ACTIVITY*

By L. V. Berkner and S. L. Seaton

Systematic changes of maximum electron-density associated with geomagnetic disturbance have been difficult to isolate owing to the lack of sufficient homogeneous data. It is well known that intense magnetic storms are associated with marked ionospheric changes. The purpose of this investigation is to determine the nature of systematic changes of maximum ion-density of F_2-layer which accompany geomagnetic disturbance of all ranges of intensity at several latitudes.

Appleton, Naismith, and Ingram [see 1 of "References" at end of paper] have shown that at Tromsö and at Slough there are, associated with geomagnetic disturbance, characteristic variations in F_2-layer which change with season. Similar changes have been observed at the Kensington (Maryland) Experimental Station and described qualitatively [2]. In the present investigation we consider about two years of continuous observations made at the Watheroo and Huancayo magnetic observatories of the Department of Terrestrial Magnetism utilizing automatic multifrequency technique described elsewhere [3, 4]. A convenient quantitative measure, namely, deviation of daily average maximum electron-density from normal, has been derived and compared to associated geomagnetic activity for each day.

It is first necessary to establish some "normal" from which deviations can be measured. Maximum ion-density of F_2-layer varies in a complicated way depending upon hemisphere, latitude, time of year, sunspot-number, and other factors, as well as upon associated geomagnetic activity. No analytical expression has yet been derived, either theoretically or empirically, which reasonably approximates the observed data. A suitable normal therefore can not yet be established through purely analytica processes. Deviations from monthly mean values are not satisfactory because large systematic changes in maximum ion-density take place in a single month. We have, therefore, arbitrarily adopted the following "normal." Monthly values of electron-density, $\overline{N}_M$, are formed from the sum of all hourly values during the month. These are determined from

$$\overline{N}_M = \frac{k}{24M} \sum_{n=0}^{n=M} \sum_{n=0}^{n=24} (f^0)^2 \qquad (1)$$

where f^0 represents the value of penetration-frequency in mc/sec scaled at each hour, $k = 1.24 \times 10^4$, and M is the number of days used during the month. All days having an American magnetic character-figure (C_A) of 1.6 or greater, as well as the day immediately following, have been rejected from the mean because such days occur infrequently and might affect the mean in an irregular way. Smooth curves are then drawn through these monthly mean values, establishing the normal for each day. Normal values for each day are scaled from the graph. These graphs are shown for the Huancayo Magnetic Observatory in Figure 1 and for the Watheroo Magnetic Observatory in Figure 2.

*Presented at joint meeting of International Union of Scientific Radiotelegraphy and Institute of Radio Engineers at Washington, D. C., April 30, 1940.

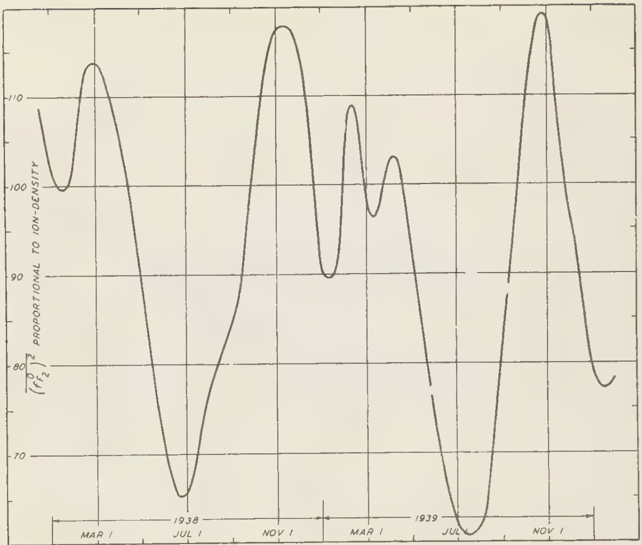


FIG. 1—VARIATION OF 24-HOUR AVERAGE F_2-REGION ION-DENSITY DERIVED FROM MONTHLY MEANS REPRESENTING NORMAL CONDITIONS AT HUANCAYO MAGNETIC OBSERVATORY (LATITUDE 12°S, LONGITUDE 75°W)

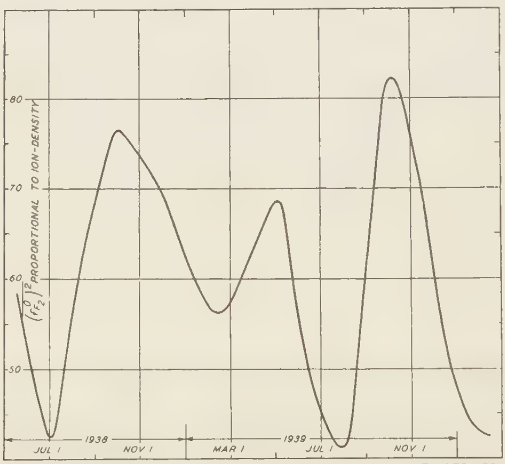


FIG. 2—VARIATION OF 24-HOUR AVERAGE F_2-REGION ION-DENSITY DERIVED FROM MONTHLY MEANS REPRESENTING NORMAL CONDITIONS AT WATHEROO MAGNETIC OBSERVATORY (LATITUDE 30°S, LONGITUDE 116°E)

The average maximum electron-density over each day, N_D, is taken as the average of the hourly observed values

$$\overline{N}_D = \frac{k}{24} \sum_{n=0}^{n=24} (f^0)^2 \tag{2}$$

Deviations from the normal for each day are therefore

$$\overline{\triangle N_D} = (\overline{N}_D - \overline{N}_M) = k\overline{\triangle f_D^2} \qquad (3)$$

We have used the American magnetic character-figure, C_A, as the measure of magnetic activity. This character-figure is given for the Greenwich day. At Huancayo, the deviation of 24-hourly averages of maximum electron-density from normal, $\overline{\triangle N_D}$, is referred to the local day which commences five hours after the beginning of the Greenwich day for which C_A is available. At Watheroo, $\overline{\triangle N_D}$ is referred to the local day minus 12 hours. This day begins four hours after the beginning of the Greenwich day, or one hour before the corresponding day at Huancayo. In comparing $\overline{\triangle N_D}$ at the two observatories, the difference of one hour is not considered serious. In comparison of $\triangle N_D$ with C_A, time-differences of five and four hours for Huancayo and Watheroo, respectively, arise. These are hardly avoidable without excessive reworking of the data. We believe that this difference will not greatly affect the result because of the tendency of magnetic activity to change in character but slowly with time. With the advent of the new three-hour-range magnetic index K, it will be possible in the future to utilize a measure which practically avoids this difficulty.

In practice, the constant, k, which relates electron-density to the square of penetration-frequency, is dropped for convenience and the values $\overline{\triangle f_D^2}$ are used. These can be readily converted to actual values of electron-density when desired. The procedure involves tabulation of $\overline{\triangle f_D^2}$ under C_A for that day. Days are separated into 11 magnetic-character ranges, namely, 0.0-0.1, 0.2-0.3,........1.8-1.9, and 2.0. Under each magnetic range are tabulated values of $\triangle f_D^2$ for days falling within that magnetic range. The average deviation, $\overline{\triangle f^2}$, is then taken for each range of geomagnetic activity.

The results are summarized in Figure 3 which shows the average deviation from normal, $\overline{\triangle f^2}$, with respect to magnetic activity at both Watheroo and Huancayo. The first column of Figure 3 relates to observations during the months of September to April, while the second colum refers to observations during the months of May to August. The final column refers to all the data. The number of days used to determine each point is shown just above the point at the upper margin.

At Huancayo, electron-density at level of maximum increases continuously as magnetic activity increases up to character-figure 2.0. We place no great emphasis on the slight break in the curve, because of the small number of days during which great magnetic activity occurred. It is significant, however, that the break in the curve remains when the data are separated into two parts. There appears to be little if any seasonal change in the character of the relation at Huancayo.

At Watheroo, the relation is quite opposite to that at Huancayo during months between September and April (generally speaking, in the summer months at Watheroo). Here the average ion-density at level of maximum falls continuously as magnetic activity increases. During the winter months, electron-density rises for slight to moderate magnetic activity, and then falls as magnetic changes become severe. The relation at Watheroo between maximum electron-density of F_2-region and geomag-

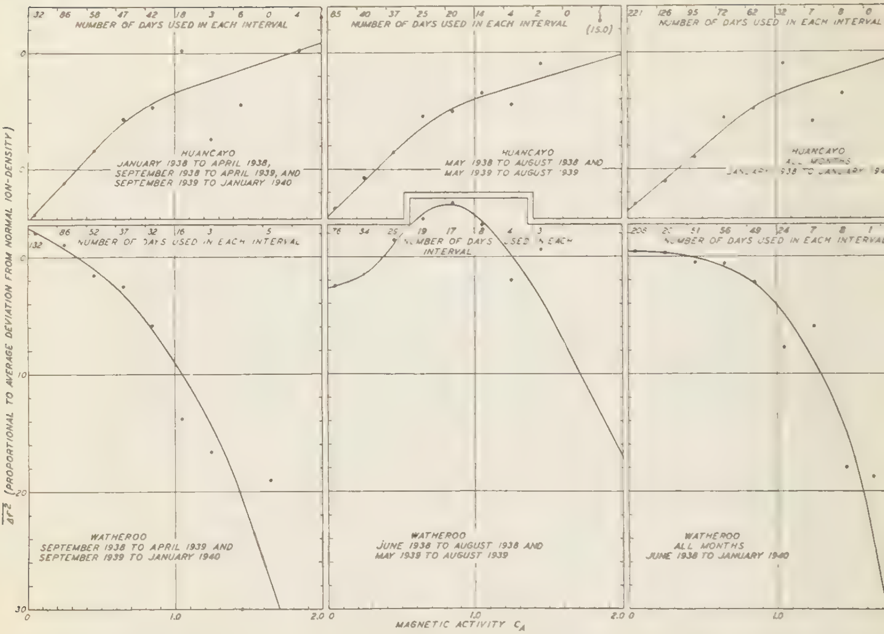


FIG. 3—AVERAGE DEVIATION FROM NORMAL F_2-REGION ION-DENSITY FOR DIFFERENT RANGES OF MAGNETIC ACTIV AT WATHEROO AND HUANCAYO MAGNETIC OBSERVATORIES ILLUSTRATING CHANGE WITH SEASON

netic activity appears very similar to that already described for Kensington [2] for the same seasons. Likewise, it agrees with the earlier observations of Appleton and his colleagues at Tromsö and Slough. It is probable, therefore, that the curves for Watheroo can be considered generally representative of the seasonal change in average maximum electron-density of the F_2-region with geomagnetic activity in both north and south temperate zones, and perhaps, to some extent also, in polar regions.

It is perhaps surprising to find that ion-density is related to even the smallest magnetic activity, for the curves show definite significant changes at both observatories down to magnetic-character zero. This indicates with certainty that the small magnetic character-figures, reported for relatively quiet days, are significant. As a consequence, the normal does not occur for $C_A = 0$, but during most months for $C_A = 0.3$ to 0.4. In winter at Watheroo, normal is reached again for values of C_A in the neighborhood of 1.3 with relatively small deviations from normal for magnetic character less than 1.3. It must be realized, of course, that the level of magnetic activity at which normal occurs must be dependent upon the average level of magnetic activity over the interval.

Electron-densities during daylight are generally 5 to 20 times those observed at night. As a consequence, the data shown are influenced principally by observations during daylight. Therefore, the extent to which the night conditions are represented by these curves must remain

in question until further analyses can be made utilizing the three-hour-range magnetic index, K.

The curves for Huancayo do not take into account the marked reduction in electron-density of F_2-layer reported during the great magnetic storms of April 16, 1938, and March 24, 1940. It seems probable that on the scale of magnetic character-figure, C_A, such storms should be rated well above the present limit of 2.0. Thus, somewhere above 2.0 the curve may drop abruptly to take account of this situation, representing the marked decrease in density which occurs during the most severe magnetic storms. However, the tendency for maximum density to oscillate between high and low values on such occasions prevents serious depression of the mean over an interval of 24 hours [5].

In conclusion, it is interesting to observe that radio-transmission conditions in daytime through the temperate zones must be more uniform during the winter months when small to moderate ranges of magnetic activity are associated with only small changes of electron-density. Indications are that in the equatorial belt conditions of transmission are improved with increasing magnetic activity until the most severe magnetic storms are experienced.

References

[1] E. V. Appleton, R. Naismith, and L. J. Ingram, Phil. Trans. R. Soc., A, **236**, 191-259 (1937).
[2] L. V. Berkner, H. W. Wells, and S. L. Seaton, Terr. Mag., **44**, 283-311 (1939).
[3] L. V. Berkner, H. W. Wells, and S. L. Seaton, Trans. Edinburgh Meeting, 1936; Inernat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. 10, 340-351 (1937).
[4] L. V. Berkner, Trans. Washington Meeting, 1939; Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. 11, 417-437 (1940).
[5] L. V. Berkner and S. L. Seaton, Terr. Mag., **45**, 393-418 (1940).

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

(See also page 513)

PROVISIONAL SUNSPOT-NUMBERS FOR JULY TO SEPTEMBER, 1940

(Dependent alone on observation at Zürich Observatory)

Day	July	August	September
1	91	69	$E130^{abc}$
2	67	60	110
3	77	67^{d}	125
4	47	$E105^{ac}$	95^{ab}
5	$E56^{c}$	103	$W91^{ac}$
6	$M44^{c}$	111^{d}	89^{a}
7	56^{a}	$E121^{c}$	$E68^{c}$
8	$M68^{cc}$	119^{a}	62
9	$E97^{ac}$	129^{a}	42
10	$M122^{cd}$	148	...
11	125^{a}	$E128^{acd}$	...
12	126	124^{a}	38^{a}
13	101	162^{d}	$E37^{c}$
14	76	128	41
15	62	110	$M32^{c}$
16	74^{a}	$E98^{ac}$	50^{a}
17	$W60^{c}$	109^{a}	$E56^{cd}$
18	62	114	79
19	66	$E97^{ac}$	100^{bd}
20	67	$E126^{acd}$	98
21	52	...	106^{d}
22	$M58^{c}$	126	93
23	34^{a}	116^{a}	66
24	34	94	...
25	$E48^{c}$	84	...
26	37	$E71^{ac}$	...
27	$E\ldots^{c}$	75^{d}	26^{a}
28	59^{d}	76	37
29	53^{a}	89^{dd}	38
30	59	89	...
31	$M67^{aac}$	99^{a}	
Means......	68.2	104.9	71.2
No. days....	30	30	24

Mean for quarter, July to September, 1940: 82.2 (84 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disk; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

SPHERICAL HARMONIC ANALYSIS OF THE S_q-VARIATIONS, MAY-AUGUST 1933

By N. P. Benkova

§ 1. The present paper gives the results of the spherical harmonic analysis of the quiet solar diurnal variations (S_q) of the Earth's magnetic field for the summer months, May to August, 1933. Schuster [see 1 of "References" at end of paper] was the first to apply in 1889 Gauss's expansion in terms of spherical harmonics to the analysis of diurnal variations. The spherical harmonic analysis of the Earth's permanent and transient magnetic fields is of the utmost importance, first, because it permits generalizing the empirical data in the form of an analytical expression and, second, because it offers information regarding the structure of this field (its potential and its origin). The spherical harmonic analysis of the diurnal variations has therefore been repeatedly undertaken by many investigators [2 to 7]; but from time to time, with accumulation of new observational data (of greater reliability, or referring to other epochs), it becomes desirable to have recourse to new analyses.

The present analysis deals with the normal diurnal variations of the three components of the Earth's magnetic field, as recorded at 46 stations during the summer months (May to August) of 1933 (Table 1). For

Table 1

o.	Station	Latitude, ϕ	Longitude, λ	No.	Station	Latitude, ϕ	Longitude, λ
		° ′	° ′			° ′	° ′
*1	Bukhta Tikhaja...	80 18N	52 45E	24	Karsani..........	41 50N	44 42E
*2	Dickson..........	73 30N	80 30E	25	Tashkent.........	41 20N	69 18E
*3	Matochkin Shar...	73 16N	56 30E	26	Ebro.............	40 49N	0 30E
*4	Tromsö..........	69 40N	18 57E	**27	Cheltenham......	38 44N	76 51W
*5	Sodankylä........	67 22N	26 39E	28	Kakioka.........	36 14N	140 11E
*6	Kandalakscha.....	67 08N	32 26E	**29	Tsingtao.........	36 04N	120 19W
7	Fort Rae.........	62 50N	116 06W	**30	Tucson...........	32 51N	110 50W
8	Dombås..........	62 05N	9 06W	31	Zô-Sè............	31 06N	121 11E
9	Lerwick..........	60 08N	1 11W	**32	Helwan..........	29 52N	31 21E
l0	Sloutzk..........	59 41N	30 29E	33	Hongkong........	22 27N	114 03E
.1	Lovö............	59 21N	17 50E	**34	Honolulu.........	21 19N	158 04W
.2	Sitka............	57 03N	135 20W	**35	Teoloyucan.......	19 45N	99 11W
l3	Visokaja Dubrawa.	56 44N	61 04E	36	Bombay.........	18 54N	72 49E
l4	Saymistche (Kasan)	55 50N	48 51E	**37	San Juan.........	18 23N	66 07W
l5	Eskdalemuir......	55 19N	3 12W	38	Kuyper..........	6 02S	106 44E
l6	Meanook.........	54 37N	113 21W	39	Elisabethville.....	11 40S	27 28E
l7	Zouy............	52 28N	104 02E	40	Huancayo........	12 03S	75 20W
l8	Swider...........	52 07N	21 15E	41	Apia.............	13 48S	171 46W
l9	De Bilt..........	52 06N	5 11E	42	Mauritius........	20 06S	57 36E
20	Abinger..........	51 11N	0 23W	43	Watheroo........	30 19S	115 53E
21	Val Joyeux.......	48 49N	2 01E	**44	Cape Town.......	33 57S	18 28E
22	Toyohara........	46 57N	142 45E	45	Toolangi.........	37 32S	145 28E
23	Maytun..........	43 15N	132 20E	46	Christchurch......	43 10S	172 43E

Note.—The data referring to the stations marked with an asterisk have been communicated by V. Pushkov, Director of the Central Institute of Terrestrial Magnetism at Sloutzk. The data with o asterisks were kindly supplied by D. la Cour of the Geophysical Observatory at Rude Skov. The re-ining data were taken from publications of the corresponding stations. Those for Maytun Station refer 1934. A comparison of the variations for 1933 and 1934 at the Zouy and Kakioka stations showed that oticeable difference for these two years could hardly be expected.

stations Nos. 9-46, the average diurnal variations for 20 international quiet days were used [8]. For the polar stations Nos. 1 to 6 and 8, the diurnal variations calculated by Birkeland's [9] method were taken, and for station No. 7 the diurnal variations recorded on the quietest days [10].

An inspection of the characteristics of the magnetic field [8] and the comparison of the diurnal variations to be used with disturbed variations showed that, with a few exceptions (vertical component at Meanook and Buchta Tikhaja and horizontal component at Fort Rae) the diurnal variations so selected were actually quiet and free from any disturbing effects.

The analysis was based on the assumptions that: (1) The field of the S_q-variations is a function of time and of two spherical co-ordinates; (2) the S_q-field can be analyzed in two parts, one depending on local time and the other on universal time; (3) this field has its origin both above and below the Earth's surface. Accordingly, it was assumed that the S_q-field may be represented in the form

$$S_q = F_1(t, \theta) + F_2(T, \lambda, \theta)$$

where t is the local solar time, θ is the geographical colatitude, λ is the geographical longitude, and T is the international (Greenwich) time (GMT).

§ 2. We shall first consider the function $F_1(t, \theta)$. Let us assume $F_1 = -\text{grad } V_1$ and represent V_1 in the form

$$V_1 = R \sum_{n=1}^{\infty} \sum_{m=0}^{n} (I_n^m \cos mt + i_n^m \sin mt)(R/r)^{n+1} P_n^m \cos \theta$$
$$+ R \sum_{n=1}^{\infty} \sum_{m=0}^{n} (E_n^m \cos mt + e_n^m \sin mt)(r/R)^n P_n^m \cos \theta \qquad (1)$$

where R is the radius of the Earth (assumed to be a sphere), I_n^m, i_n^m, E_n^m, and e_n^m are empirical constants, r is the radius-vector, and $P_n^m(\cos \theta)$ is an associated Legendre function of the first kind, determined by the expression

$$P_n^m (\cos \theta) = 1{\cdot}3{\cdot}5 \;.\;.\;.\;.\; (2n-1) \sqrt{\frac{\epsilon_m}{(n+m)!\;(n-m)!}} \sin^m \theta$$
$$\times \left(\cos^{n-m}\theta - \frac{(n-m)(n-m-1)}{2(2n-1)} \cos^{n-m-2}\theta + \;.\;.\;.\;.\;.\;.\; \right) \qquad (2)$$

where $\epsilon_m = 2$ for $m \geqslant 1$ and $\epsilon_0 = 1$. At the Earth's surface $R = r$ and

$$V_1 = R \sum_{n=1}^{\infty} \sum_{m=0}^{n} (t, g_n^m, h_n^m) P_n^m \qquad (3)$$

where P_n^m stands for P_n^m (cos θ), the symbol (t, g_n^m, h_n^m) stands for the expression $(g_n^m \cos mt + h_n^m \sin mt)$ and

$$g_n^m = E_n^m + I_n^m \qquad h_n^m = e_n^m + i_n^m \qquad (4)$$

The rectangular components of grad V_1 are

$$\delta X_1 = \frac{1}{R}\frac{\partial V_1}{\partial \theta} \qquad \delta Y_1 = -\frac{1}{R \sin \theta}\frac{\partial V_1}{\partial t} \qquad \delta Z_1 = \frac{\partial V_1}{\partial r} \qquad (5)$$

if the positive OX-axis points to the geographical north, the OY-axis to the east, and the OZ-axis vertically downward.

In the above notation

$$\left.\begin{aligned}
\delta X_1 &= \sum_{n=1}^{\infty} \sum_{m=0}^{n} (t, g_n^m, h_n^m) \frac{dP_n^m}{d\theta} \\
\delta Y_1 &= \sum_{n=1}^{\infty} \sum_{m=0}^{n} (t, -h_n^m, g_n^m) \frac{mP_n^m}{\sin\theta} \\
\delta Z_1 &= \sum_{n=1}^{\infty} \sum_{m=0}^{n} (t, j_n^m, k_n^m) P_n^m
\end{aligned}\right\} \tag{6}$$

Here

$$j_n^m = (nE_n^m - (n+1)I_n^m) k_n^m = ne_n^m - (n+1)i_n^m \tag{7}$$

For each station the observed variations of the geographical components δX, δY, and δZ of the magnetic field were represented in the form of Fourier series in local time

$$\left.\begin{aligned}
\delta X &= \sum_m (a_m^X \cos mt + b_m^X \sin mt) \\
\delta Y &= \sum_m (a_m^Y \cos mt + b_m^Y \sin mt) \\
\delta Z &= \sum_m (a_m^Z \cos mt + b_m^Z \sin mt)
\end{aligned}\right\} \tag{8}$$

For stations differing little in latitude the coefficients $a_m^X \ldots b_m^Z$, which will be referred to as the "observational coefficients," were averaged graphically.*

The average values of $a_m^X \ldots b_m^Z$ so obtained were regarded as free from the influence of the field F_2 and were used as a basis for the computation of the coefficients $g_n^m \ldots k_n^m$ of the potential V_1 by means of Schuster's method [1]. The coefficients g_n^m, h_n^m were calculated separately from the variations of the north and the east components and meaned.

Leaving aside the question as to whether a part of the field depends on longitude, it may be noted that the field depending on local time, considered above, constitutes the major part—about 80 per cent—of the total field.

Table 2 gives the coefficients $g_n^m \ldots k_n^m$ for $m=1$, 2 and for $n=1, \ldots 5$.

TABLE 2

n	g_n^m		h_n^m		j_n^m		k_n^m	
	$m=1$	$m=2$	$m=1$	$m=2$	$m=1$	$m=2$	$m=1$	$m=2$
1	3.93		−3.18		0.09		−0.24	
2	7.12	−1.19	−2.38	2.52	3.79	0.46	−0.60	1.00
3	0.58	−3.72	0.50	2.04	3.34	−3.55	−0.22	1.28
4	−2.10	−0.92	0.07	0.22	−1.61	−4.19	−0.96	−0.24
5	−0.64	0.80	0.28	0.09	−3.20	0.81	−0.20	−0.96

*When computing average values, the observational coefficients δX for the Fort Rae Station and δZ for the Meanook and Bukhta Tikhaja stations were omitted.

§ 3. With the aid of expressions (4) and (7) the coefficients E_n^m, I_n^m, e_n^m, and i_n^m were determined from the values of g_n^m . . . . k_n^m. A comparison of the amplitudes $c_i=\sqrt{I^2+i^2}$ of the internal part of the field with those $c_e=\sqrt{E^2+e^2}$ of the external field shows the latter to be on the average some 2.1 times as great as the former. This result is in good agreement with Chapman's [6] conclusions, confirming the statement that the main part of the S_q-field is a potential field having an external origin.

As is well known, a magnetic field having its origin above the Earth's surface can be regarded as the magnetic field of an electric spherical shell of currents with a radius $r>R$ [12]. Assuming that the electric currents, which are equivalent to the external part of the field F_1, circulate in the lower layers of the ionosphere, let us construct a chart showing the distribution of the electric current-function for $r=1.02R$ (Fig. 1). The lines on Figure 1 are drawn in such a way that a 10,000 ampere-current flows between two neighboring lines. A comparison of Figure 1 with the well-known current-system given by Bartels-Chapman [12] shows that the author's system B is, in the main, in good agreement with Chapman's system C. Still, there are certain rather essential differences.

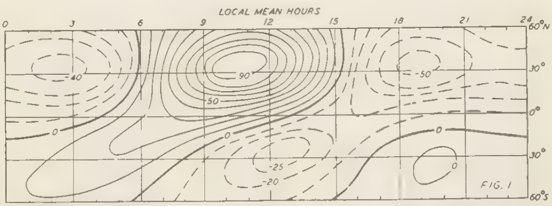


FIG. 1

In system B the circulation on the sunlit side of the Northern Hemisphere is more intense, the southern circulation by day being less intense, than the corresponding circulations in system C. In the latter, the center of the southern day-circulation corresponds to $12^{\mathrm{h}}\,30^{\mathrm{m}}$, in system B to 11^{h}. Furthemore, differing from system C, the dark region of the negative circulation in system B splits up into two separate circulations. These discrepancies are probably due to the fact that the two systems have been based on different records, their analytical treatment being also different.

§ 4. The values of a_m^X . . . . . . b_m^Z for each station were next derived from the coefficients g_n^m . . . . k_n^m originally obtained for the components X and Y. The function $F_2(T, \lambda, \theta)$ was determined on the basis of the differences $\triangle a_m^X$ . . . . $\triangle b_m^Z$ between the corresponding observed and calculated Fourier coefficients. From a formal point of view, the computation of the field F_2 should be based on the differences between the observed Fourier coefficients for different stations and the average values for corresponding latitudes. However, the function F_1 was found to represent quite satisfactorily a field depending on θ and on t, and therefore the possible inaccuracy involved through using the adopted method of calculating values for the field F_2 could be neglected.

Let us assume that $F_2=-\mathrm{grad}\ V_2$ and that the rectangular components of the vector F_2 can be expressed as

$$\left.\begin{aligned}\delta X_2 &= \sum_s (A_s^X \cos sT + B_s^X \sin sT)\\ \delta Y_2 &= \sum_s (A_s^Y \cos sT + B_s^Y \sin sT)\\ \delta Z_2 &= \sum_s (A_s^Z \cos sT + B_s^Z \sin sT)\end{aligned}\right\} \qquad (9)$$

where $A_s^X \ldots . B_s^Z$ are functions of θ and λ. If $A_s^X \ldots . B_s^Z$ are expressed in the form of series of spherical functions, the following expression will be obtained for V_2 at the Earth's surface

$$\begin{aligned}V_2 = R \sum_s [\sum_n \sum_m \ (\lambda, l_{ns}^m, r_{ns}^m) P_n^m \cdot \cos sT + \\ + \sum_n \sum_m (\lambda, p_{ns}^m, q_{ns}^m) P_n^m \cdot \sin sT]\end{aligned} \qquad (10)$$

whence

$$\left.\begin{aligned}A_s^X &= \sum_n \sum_m (\lambda, \ l_{ns}^m, \ r_{ns}^m) \frac{\mathrm{d}P_n^m}{\mathrm{d}\theta}\\ B_s^X &= \sum_n \sum_m (\lambda, p_{ns}^m, q_{ns}^m) \frac{\mathrm{d}P_n^m}{\mathrm{d}\theta}\\ A_s^Y &= \sum_n \sum_m (\lambda, -r_{ns}^m, l_{ns}^m) \frac{mP_n^m}{\sin\theta}\\ B_s^Y &= \sum_n \sum_m (\lambda, -q_{ns}^m, p_{ns}^m) \frac{mP_n^m}{\sin\theta}\\ A_s^Z &= \sum_n \sum_m (\lambda, t_{ns}^m, u_{ns}^m) \ P_n^m\\ B_s^Z &= \sum_n \sum_m (\lambda, v_{ns}^m, w_{ns}^m) \ P_n^m\end{aligned}\right\} \qquad (11)$$

From the values of the coefficients $A_s^X \ldots . B_s^Z$ which were obtained by simple operations on $\triangle a_s^X \ldots \ldots \triangle b_s^Z$, the quantities $l_n^m \ldots . w_n^m$ were calculated, using again, as in the case of field F_1, the method proposed by Schuster. The values of $l_n^m \ldots . w_n^m$ were derived from the variations of the north and east components separately, and the coefficients of the field F_2 were obtained by the coefficients determined from δX_2 and from δY_2. The maximum value of the differences $\triangle a_s^X \ldots . \triangle b_s^Z$ corresponded to $s=1$, so that the analysis was restricted to the terms with the subscript-index $s=1$. Accordingly, in Table 3 giving the coefficients $l_n^m \ldots . w_n^m$, the subscript-index has been omitted. Computation showed that for a satisfactory representation of the observed field F_2, it suffices to retain the terms up to $n=5$ and $m=3$, inclusive.

A comparison of Tables 2 and 3 shows that the dimensions of field F_2 are considerably smaller than those of field F_1, so that it must be regarded as a correction to the analytical expression for Sq.

Similarly as in the case of field F_1, the field F_2 was separated into two portions having their origin above and below the Earth's surface. The former part proved to be 1.7 times larger than the latter. A similar calculation was made for the system of external electric currents which could be made responsible for the external part of field F_2. In order to get

References

[1] A. Schuster, Phil. Trans. R. Soc., A, **180**, 467-512 (1889); **208**, 163-204 (1907).
[2] H. Fritsche, St. Petersburg (1902).
[3] W. van Bemmelen, Met. Zs., **29**, 218-230 (1912).
[4] G. W. Walker, Proc.R. Soc., A, **89**, 379-392 (1914).
[5] A. van Vleuten, K. Ned. Met. Inst., No. 102, 112 pp. (1917).
[6] S. Chapman, Phil. Trans. R. Soc., A, **218**, 1-118 (1919).
[7] A. G. McNish, Trans. Edinburgh Meeting, 1936; Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, 271-280 (1937).
[8] Caractère magnétique de chaque jour des mois avril-juin 1933, De Bilt (1934); L'Année Polaire Internationale 1932-1933, De Bilt (1937).
[9] O. Krogness and K. F. Wasserfall, Pub. Inst. Kosmisk Fysikk, No. 9 (1936).
[10] British Polar Year Expedition Fort Rae, Northwest Canada, 1932-1933, London (1937).
[11] A. Schuster, Phil. Trans. R. Soc., A, **200**, 181-223 (1903).
[12] G. Angenheister und J. Bartels, Das Magnetfeld der Erde, Handb. Exp. Physik, **25**, I, 525-684 (1928).

INSTITUTE OF TERRESTRIAL MAGNETISM,
CENTRAL ADMINISTRATION OF HYDROMETEOROLOGICAL SERVICE,
Sloutsk, U.S.S.R., June 26, 1940

Editor's note: An interesting comparison of Benkova's results with those of previous analyses is given in Table *A*

TABLE *A—Value of coefficients* c_n^m, α_n^m *for various analyses of* S_q; $c_n^m = n\sqrt{\{(g_n^m)^2+(h_n^m)^2\}}$ *and tan* $\alpha_n^m = -h_n^m/g_n^m$

Coefficient	Chapman		Schuster	Fritsche	Benkova
	1902	1905	1870		Summer, 1933
c_2^1	13.9	20.1	30.9	20.5	15.0
α_2^1	35°	24°	24°	30°	19°
c_3^2	13.4	17.6	21.3	14.4	12.7
α_3^2	215°	207°	211°	205°	209°
c_1^1	4.3	4.7	5.4	5.9	5.0
α_1^1	23°	27°	27°	28°	39°
c_3^1	6.2	8.4	7.4	4.5	2.3
α_3^1	344°	337°	311°	347°	318°
c_2^2	4.2	6.0	7.8	5.8	5.6
α_2^2	243°	243°	255°	242°	244°
c_4^2	4.6	3.7	3.5	3.9	3.8
α_4^2	205°	210°	162°	186°	194°

NOTES ON ISOMAGNETIC CHARTS: I THEIR SINGULAR POINTS AND CONTOUR-LINES

By S. Chapman

Abstract—Some aspects of the geometry of isomagnetic charts (using *isomagnetic* in a wide sense) are considered, particularly as regards their ray-poles and singular points—foci and nodes. Special types of singular points are shown to include circular foci, rectangular nodes, and cusps. Some suggestions are made regarding the construction of isomagnetic charts.

§ 1. *Purpose*—The object of this paper is to discuss some points concerning the geometry of isomagnetic and other contour-lines on a sphere, and, in particular, the nature of their singular points and of the lines near these. In a later note (II) special attention will be given to the poles of magnetic dip. Some suggestions are made regarding the construction of isomagnetic charts (§ 14).

The term isomagnetic will here be used in a generalized sense, referring to lines along which any scalar property of the surface geomagnetic field is constant; thus it includes the lines ordinarily called isomagnetic, along which a scalar magnetic element (F, H, Z, I, D, X, Y) has a constant value; it will also include isanomals, along which the anomaly of a magnetic element, relative to some defined normal distribution, is constant; likewise it includes isopors, or lines of equal rate of secular change of a magnetic element; it will also include equipotential lines, along which the surface-value of the magnetic potential is constant—either the whole potential, or the potential of some component part of the field, such as that of S, L, or D, the fields of the solar and lunar daily variations, and of magnetic disturbance; it will also include the electric current lines for current-systems in the ionosphere or in some layer within the Earth, since the lines of steady current-flow in a current-sheet are lines along which a certain function of position (the current-function) is constant.

In a later note on magnetic dip-poles we shall also consider the magnetic meridians or lines of horizontal magnetic force **H** which at each point have the same direction as **H** there.

THE CONTOUR-LINES AND SURFACE

§ 2. *Contour-lines*—Isomagnetic lines are examples of *families of contour-lines or contour-families*. A contour-family is associated with a scalar function of position f defined at all points of a spherical surface (for example, the Earth's surface or, in the case of the current-lines, the ionospheric layer in which the current flows); in some cases (not considered in this paper) f may be defined over only a part of the sphere. The contour lines are the lines.

$$f=c \tag{1}$$

where for any one line c is a constant; it is called the parameter of the line. One contour passes through each point P of the surface, namely the contour for which c has the value of f at P.

Much of the following discussion of the geometry of contour-families can readily be generalized to apply to contour-families on surfaces which are not spherical. Obviously the function $-f$, and also the functions

$\pm(f+C)$, where C is a constant, have the same contour-family as the function f, the only difference being in the sign or magnitude of their parameters c. We shall regard these families as essentially the same.

§ 3. *The contour-surface*—Let S denote the spherical surface over which f is defined; let O be the center and a the radius of S. We suppose that f is finite all over S, and, usually, that f is everywhere ***regular***, meaning by this that it is continuous, with continuous gradients, and single valued, though for some of the magnetic elements these conditions are violated at particular points (§ 6).

The distribution of f over S can be represented by means of a surface S', called the *contour-surface*, defined as follows: Any radius of S, say OP, cuts S' in a point P' such that

$$OP' = a + \epsilon f$$

where f here signifies the value at P, and ϵ is a positive constant sufficiently small to make ϵf everywhere numerically less than a. Evidently S', O, a, and ϵ together specify the function f, because $f = PP'/\epsilon$, taking PP' positive or negative according as OP' or OP is the greater.

It is convenient to refer to the *level* of points on S', as signifying their distance from O; points on S' will be said to lie at a higher or lower level according as they are further from or nearer to O. The words *vertical* and *horizontal* will be used to signify, at any point P or P' on S or S', the *radial* direction, and directions *normal* to the radius.

§ 4. *Contour-sections, cones, and lines*—The surface of any sphere with center O and radius r may completely surround S', or may lie completely inside S'; if it does neither, then it will cut S' in a closed curve or curves, which together will be called the *contour-section C' of S' at the level r* (or, more briefly, the *contour-section r*). As a special case C' may reduce to a single point P, namely when r is equal to the absolute maximum value r_1 or the absolute minimum value r_2 of $(a+\epsilon f)$; the sphere then touches S' at P, where the tanget plane to S' must be horizontal. It is convenient to refer to the spheres of radius r as *section-spheres*.

In special cases the surface S may include *areas* over which r is constant, as in the case of the oceans on a contour-map of height above or below sea-level. Such areas may be called *contour-areas*.

A cone or cones, together called the *contour-cone for the level r* (or the *contour-cone r*), may be defined as having the vertex O and passing through the contour-section C'. The contour-cone will cut the sphere S in a curve or curves which together constitute the *contour-line C* whose parameter c is $(r-a)/\epsilon$.

As the section-sphere shrinks in radius from the maximum value r_1 to the minimum value r_2, it generates the contour-sections at all the levels of S'; the corresponding contour-cones generate the whole contour-family on S.

The contour-cones will also generate a similar contour-family on any concentric sphere of radius a', with merely a change of linear scale, in the ratio (a'/a). Often we are interested only in the *form* of the contour-family; if so, we should regard the contour-families on the spheres of radii a and a' as identical.

§ 5. *Intrinsic and relative functions and contour families*—If the function f, by definition, involves reference to some system of coordinates of position on S, it and its contour-family will be called *relative*—other-

wise they will be called *intrinsic*.* Examples of intrinsic functions and intrinsic contour-families are the magnetic elements F, H, Z, I and their isomagnetic lines, as also the magnetic potential and its equipotential lines, and the current-function and its current-lines; all these are independent of any reference-system of position on S.

The magnetic elements D, X, and Y, on the other hand, are relative, because their definition depends on the choice of the geographical north pole as a *reference-pole*, and on the geographic meridians as defining a horizontal *reference-direction* at any point on S.

§ 6. *Points of undefined but multiple limiting value; ray-poles*—The magnetic declination D, which is the angle between the horizontal magnetic vector $\mathbf{H}$ and the meridianal reference-direction at the point considered, is indeterminate at the reference-pole and its antipode (the geographical northern and southern poles), and also at points where $\mathbf{H}$ vanishes. This is because either the reference-direction, or the direction of the vector $\mathbf{H}$, is undefined at such points. At any adjacent point, however, D is defined; and as we go round any small circle on S, centered at a reference-pole or its antipode, the reference-direction takes all values, so that D ranges from 0° to 360°. Hence as such a pole is approached radially from different directions, D tends to different limits, having a finite range of values (360°). The pole is therefore a point of multiple (limiting) value, and *all* the contour-lines, for the whole possible range of values of c (0° to 360°), must meet there. A point which is approached radially by all the contour-lines of a function f that pass through a small circle centered at the point, so that f has a *range* of limiting values there, is an essential singularity of the contour-family; it will be called a *ray-pole*. If the function f varies uniformly round any sufficiently small circle centered at the ray-pole, this will be called a *uniform* ray-pole. The isogonic (D) chart has a *uniform* ray-pole at each of the geographic poles; as will be seen in a later Note, poles of magnetic dip may also be ray-poles, though in general they will not be so

The elements X and Y are the components of $\mathbf{H}$ along and perpendicular to the geographical reference-direction at the point considered. At the reference-poles, however, the reference-direction becomes indefinite, and unless these points are dip-poles, where $H = 0$ (which is not the case for the geomagnetic field), they are ray-poles for X and Y. As the north reference-pole, for example, is approached from different directions, X and Y tend to limiting values ranging from $-H_0$ to H_0, where H_0 is the magnitude of $\mathbf{H}$ at the pole; this is because, at near points along the radius making an angle ϕ with $\mathbf{H}$ at the pole, $X = H_0 \cos \phi$, $Y = H_0 \sin \phi$, so that X and Y are constant along any such radius ϕ; but the variation of X and Y with ϕ is not uniform, so that the reference-poles are ray-poles but not uniform ray-poles for X and Y. For X and Y the dip-poles are in general not singular points or ray-poles; X and Y merely take particular definite values there, namely zero.

Except at their ray-poles, the elements D, X, and Y, like other magnetic elements and functions (such as the potential or the current-function), are single-valued continuous functions of position on S.

For the present the succeeding discussion is limited to functions without ray-poles, or, for functions which have ray-poles, to regions ex-

*Geog. J., 53, 166-172 (1919).

cluding the ray-poles; this restriction applies in the case of the charts for D, X, Y and for their isanomals and isopors.

ORDINARY AND SINGULAR POINTS

§ 7. *The gradient-vector of f; ordinary contour-points*—In order to distinguish between points of different character with respect to the contour-family, it is convenient to revert to the original definition of the contour-family, namely the equation (1).

We consider the form of the contour-lines on S, in a region R so small that it can be treated as plane. Let P_0 be a point near the middle of R; any adjacent point P in R may be considered as lying in the tangent-plane to S, at P_0; this plane is horizontal (§ 3) since S is spherical.

It is convenient to specify the position of P by its Cartesian coordinates x, y relative to orthogonal horizontal axes through P_0, whose own coordinates, on this specification, are therefore (0, 0). Hence over the region R, the function f may be regarded as a function of x and y, written $f(x, y)$. Let f_0 denote its value, $f(0, 0)$, at P_0. Then at P, where x and y are small, we have approximately

$$f=f_0+lx+my \tag{2}$$

Here

$$l=\left(\frac{\partial f}{\partial x}\right)_0 \equiv f^\circ_x \qquad m=\left(\frac{\partial f}{\partial y}\right)_0 \equiv f^\circ_y \tag{3}$$

using the affix 0 to indicate that the values refer to the origin P_0, and the suffix x or y to indicate partial differentiation.

The contour-line through P_0, namely $f=c_0$, where $c_0=f_0$, is consequently given approximately, within R, by the equation

$$f=f_0+lx+my=c_0$$

or

$$lx+my=0 \tag{4}$$

The adjacent contour lines $f=c$, where c is any other value assumed by f in R, are given approximately, in R, by the equation

$$lx+my=(c-c_0) \tag{5}$$

wherein $(c-c_0)$ is a small quantity. The equations (4, 5) represent parallel straight lines, (4) being a line through the origin.

Outside the small region R, of course, these equations no longer represent the contour-lines approximately; the curvature of the lines, and of S, requires a modification of the equations.

No special character attaches to the case when *either l or m* is zero (but not both), because this implies merely that the countour-lines are parallel to one or other axis, P_0x or P_0y, and these have been chosen arbitrarily. The factors l and m are the x- and y-components, at P_0, of the (*surface*)* *gradient vector* of the function f on the sphere S; this vector may be denoted by $\partial f/\partial \mathbf{r}$ or $\triangle f$; it is an intrinsic vector independent of any special axes of reference at the point P_0. So long as l and m do

*The adjective *surface* indicates that $(\partial f/\partial \mathbf{r})$ is here considered as a two-dimensional vector, tangential to the sphere at the point to which it refers; if, as is usual in the case of functions f represented on isomagnetic charts, f is defined not only on the sphere, but at all points, the complete gradient vector $(\partial f/\partial \mathbf{r})$ is three-dimensional, having three components; the third component is the radial gradient of f, namely $(\partial f/\partial r)$.

not both vanish, $(\partial f/\partial \mathbf{r})$ has a definite direction; the equations (4, 5) imply that the contour-lines in the region R are perpendicular to the gradient vector at P_0.

A point at which $(\partial f/\partial \mathbf{r})$ does not vanish will be called an *ordinary point* of the contour-family; near such a point the contour-lines are, as we have shown, approximately straight, perpendicular to $(\partial f/\partial \mathbf{r})$, and therefore parallel to one another.

§ 8. *Singular points and values*—Near a point P_0 at which the gradient vector $(\partial f/\partial \mathbf{r})$ vanishes, the character of the contour-lines is quite different from that near an ordinary point of the contour-family; hence such points, which are of course exceptional, are called *singular points;* the values of f at these points will be called *singular values.*

The condition for P_0 to be a singular point is that, relative to arbitrarily chosen horizontal axes P_0x, P_0y (as in § 7), both components of $(\partial f/\partial \mathbf{r})$ vanish at P_0, namely

$$f^\circ_x=0 \qquad f^\circ_y=0 \tag{6}$$

If this is so for any one such pair of axes, then relative to any other set of axes, P_0x', P_0y', we also have

$$f^\circ_{x'}=0 \qquad f^\circ_{y'}=0 \tag{7}$$

In the present case (2) is no longer a satisfactory approximation to f even in the small region R, because, by (3) and (6) l and m are now zero, so that (2) reduces to $f=f_0$. It is therefore necessary to proceed to the next further approximation, namely

$$f=f_0+(ax^2+2hxy+by^2)/2 \tag{8}$$

where, in accordance with the notation used in (3)

$$a=f^\circ_{xx} \qquad h=f^\circ_{xy} \qquad b=f^\circ_{yy} \tag{9}$$

§ 9. *The principal axes at a singular point*—By taking new orthogonal horizontal axes P_0x', P_0y' through P_0, inclined at the angle

$$\gamma=(1/2)\tan^{-1}[2h/(a-b)] \tag{10}$$

to P_0x, P_0y, the expression $(ax^2+2hxy+by^2)$ is changed to $(a'x'^2+b'y'^2)$, where

$$a'=a\cos^2\gamma+h\sin 2\gamma+b\sin^2\gamma \tag{11}$$

$$b'=a\sin^2\gamma-h\sin 2\gamma+b\cos^2\gamma \tag{12}$$

it may also be shown that

$$a'=f^\circ_{x'x'} \qquad b'=f^\circ_{y'y'} \tag{13}$$

The new axes are called the *principal axes* at the singular point P_0.

Hence, relative to these axes, the contour-line $f=c_0$, through P_0, is approximately

$$a'x'^2+b'y'^2=0 \tag{14}$$

and the adjacent contour-lines in the region R are the central conics

$$a'x'^2+b'y'^2=2(c-c_0) \tag{15}$$

Two cases have now to be considered, according as the signs of a' and b' are alike or different.

Merely by choosing which of the two principal axes we call P_0x' and which P_0y', we may ensure that $|b'|\geqslant|a'|$, so that if we write

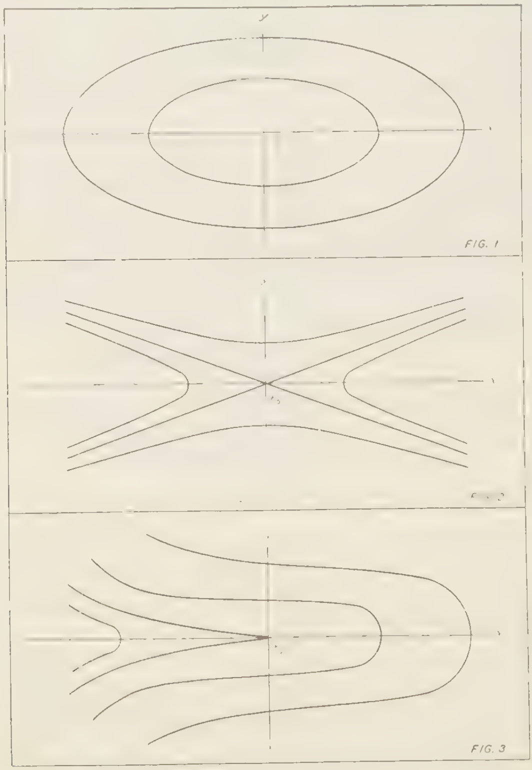
$$b'=ka \qquad k=(b'/a') \tag{16}$$

then

$$|k|\geqslant 1 \tag{17}$$

With this choice of axes, P_0x' is the major axis of the conics (15).

§ 10. *Foci and focal values*—If a' and b' have the same sign, the curves (15) are ellipses (Fig. 1), which shrink, as $c\to c_0$, to an isolated-point contour at P_0. Points P_0 of this kind, where the gradient vector $(\partial f/\partial \mathbf{r})$ vanishes, and where $f^0{}_{x'x'}$ and $f^0{}_{y'y'}$ have like signs, are called *foci* of the contour-family. In special cases we may have $a'=b'$, or $k=1$; the contour-lines near P_0 are then circles: Such a point will be called a *circular focus.*



Foci are of two kinds, according as a' and b' are both positive or both negative. In the former case, at all points x', y' near P_0, by (15), $c>c_0$, so that f has a minimum value there—a local minimum, not necessarily an absolute minimum: Such a focus is called a minimum or negative focus.

If however a' and b' are both negative, $c < c_0$ at all near points x', y', and P_0 is a maximum or positive focus.

The value of f at a focus may be called a focal value.

The points where f attains its absolute maximum and absolute minimum may be called the *principal foci*. Every regular function f has a principal maximum focus and a principal minimum focus. In special cases the "focus" may be a line or area (§ 4) instead of a point.

In § 2 it was stated that the contour-families for the functions f and $-f$ would be regarded as essentially the same. Clearly their singular points are identical; but the maximum foci of f are minimum foci of f', and *vice versa*.

§ 11. *Nodes, nodal values, and curves*—If a' and b' have opposite signs, (14) shows that the contour-line through P_0, in the small region R, approximates to two straight lines intersecting at P_0; and (15) shows that the adjacent contour-lines, in the region R, approximate to hyperbolas of which the two straight lines (14) are the asymptotes (Fig. 2). For one set of these hyperbolas $c > c_0$, and for the other set $c < c_0$. Hence P_0 in this case is not a maximum or minimum point, though the tangent plane at P_0 is horizontal; in certain directions from P_0 the function f decreases, and in others it increases: The regions of decrease from P_0 and the regions of increase from P_0 are separated by the two lines (14). Such a point P_0 is called a *node*. The (whole) contour-line $f = f_0 = c_0$ may contain one or more separate curves; any such curve which contains a node is called a *nodal curve*. The value of f at P_0 is called a *nodal value*. The term *singular value* includes both focal and nodal values.

Let P_0' denote the point on the contour-surface S', which corresponds to P_0; when the latter is a node, P_0' is a *saddle point*, resembling the summit of a "pass" between higher levels of S' on both sides of the pass. The nodal line is the projection, on S, of the level-line on S' at the level of the pass or saddle-point.

The four *nodal angles* between the two straight parts of the nodal line, where they cross at P_0, consist of two pairs of equal angles, both given by

$$2 \tan^{-1}\sqrt{|a'/b'|} \quad \text{or} \quad 2 \tan^{-1}\sqrt{|1/k|}$$

this has two values, which are supplementary, that is, their sum is π. The acute angle between P_0x and the nodal asymptote is $\tan^{-1}\sqrt{|1/k|}$, which does not exceed 45′.

In the special case in which $a' = b'$ or $k = -1$, the nodal angles are right-angles, and the adjacent contour-lines, near the node, are rectangular hyperbolas. Such a node may be called a *rectangular node*.

§ 12. *Cusps, cuspidal values and curves*—In addition to the two special types of singular point already noted, namely those at which $a' = b'$ (circular foci, § 10) or $a' = -b'$ (rectangular nodes, § 11), there is a third special type in which either a' or b' is zero. These two cases may be considered as one type, not two types, because the difference between them depends merely on the choice as to which of the two principal axes at P_0 shall be called $0x$ and which $0y$; according to our choice of axes in § 9, [illegible] k is not less than 1, so that we regard the case $k = 0$ as the standard third type.

These three special types of singular point all have [illegible] probability, since each corresponds to one particular value of k, namely $k = \pm 1$ or $k = 0$.

In order to determine the form of the contour-lines near P_0 when $k=0$ (or $a'=0$), we must consider the third-degree terms in the power-series expansion of f near P_0; subject to the special choice of axes through P_0, as in § 9, (8) must now be replaced by

$$f(x, y)=f_0+(by^2/2)+[(fx^3+3gx^2y+3hxy^2+jy^3)/6] \qquad (18)$$

where the accents attached to x, y, and b in § 9 are now dropped, and f on the right is a conotant factor, not to be confused with the same symbol used as an abbreviation for $f(x, y)$.

The contour-lines near P_0 now have the equation

$$(b/2+hx/2+jy/6)y^2+(fx/6+gy/2)x^2=f(x, y)-f_0=c \qquad (19)$$

When $b\neq 0$ (the case when *both* a and b are 0 is of a higher order of speciality than the cases here considered) the terms included with $(b/2)$ in the first bracket of (19) are negligible at points sufficiently near P_0, and will therefore be omitted. Dividing by $(b/2)$, we may write (19) in the form

$$y^2+(lx+my)x^2=2(f-f_0)/b=c \qquad (20)$$

where c is now another (small) constant, and $l(=f/3b)$ and $m(=g/b)$ have no connection with the same symbols as used in § 7. In general l and m will be finite, and both different from zero.

Let

$$l=r_0 \cos \theta_0 \qquad m=r_0 \sin \theta \qquad (21)$$

where in general r_0, like l and m, will be finite, and θ_0 will be neither 0° nor 90°. Writing

$$x=r \cos \theta \qquad y=r \sin \theta \qquad (22)$$

we have

$$lx+my=r\, r_0 \cos(\theta-\theta_0) \qquad (23)$$

and (20) becomes

$$r^2[\sin^2\theta+r\, r_0 \cos(\theta-\theta_0) \cos^2\theta]=c \qquad (24)$$

The contour-line through P_0, for which $c=0$, is therefore given by the part of the curve

$$r=[\tan^2\theta/r_0 \cos(\theta-\theta_0+\pi)] \qquad (25)$$

which lies near P_0; this consists of two branches approaching P_0 along the x-axis, both from above and from below, but only from one side of the y-axis, namely from the right (positive values of x) if $(\theta_0-\pi)$ lies between $\pm(\pi/2)$[or θ_0 between $(\pi/2)$ and $(3\pi/2)$, or l negative]; otherwise (l positive) the approach is from the left; the equation of this part of the contour-line is in fact

$$y^2+lx^3=0 \qquad (26)$$

because along it, near P_0, (y/x) is small. This is a semi-cubical parabola, as shown in Figure 3 for the case l positive.

The neighboring contour-lines near P_0 have the form shown in Figure 3. Near such a point P_0, f has the same sign everywhere except within the very small region within the cusp. Hence P_0 is almost, but not quite, a maximum or minimum point. This special type of point will be called a cuspidal point; f_0 will be called a *cuspidal* value of f. The contour-line $f=f_0$ may contain one or more separate curves; any such curve which contains a cusp will be called a *cuspidal curve.*

The three special types of singular point for which $k = \pm 1$ or $k = 0$ are doubly special points, because not only is $(\partial f/\partial \mathbf{r})$ zero there, but also k takes a special value.* Still more special points might be considered, at which either $b = 0$ as well as a' (using the notation of § 9), or at which, in (20), either l or m is zero (or, yet more special, at which two of the three factors b, l, and m are zero). These cases will not be considered here because they seem unlikely to occur in connection with geomagnetic functions.

ISOMAGNETIC CHARTS

§ 13. *Singular points on isomagnetic charts*—As has been pointed out in § 10, every regular isomagnetic chart (possibly excluding those possessing ray-poles) must have two singular points, namely a principal maximum focus and a principal minimum focus. They may also have other foci and nodes, and this is actually the case with the principal isomagnetic world charts.

The contour-lines on such charts usually refer to a regular series of simple values, differing by equal intervals, of the element considered; for example, in an isogonic chart they may be given for every degree, or every 5°. The *singular* values of the element, at the singular points, will in general not coincide with any of these special regular values of the element; hence only by a coincidence, of a rarity depending on the contour-interval and the limits of accuracy of the chart, will the regular lines include a nodal curve (an example of this is the British Admiralty world isogonic chart for 1922, on which the isogonic $D = 0$ includes a node). It may be well to recognize clearly that this is an exceptional coincidence, and not likely to recur often, owing to the continual secular change of the field.†

§ 14. *Notes on the construction of isomagnetic charts*—Though the nodal curves will thus in general not be included in the regular set of isomagnetic lines, it seems desirable, nevertheless, that the positions of each singular point (focus or node) should be indicated, and the singular value of the element there; also, in the case of a node, the part of the nodal curve near the point should be shown—its two parts which cross there will in general not be perpendicular. Near such points the element is necessarily varying slowly, and not uniformly, so that interpolation, elsewhere convenient and reasonably accurate, is there difficult; hence the need for this information to be given to the chart-user. Even if the chart-constructor cannot be sure of the position of the singular point, and of the singular value, he should be able to estimate them (by constructing suitable auxiliary graphs of the variation of the element along lines passing near the singular point) more accurately than can the chart-user. Near a focus or node one or more neighboring isomagnetic lines, at fractions of the usual interval between the regular series of values, should also be drawn; these contours will in general not be circles or *rectangular* hyperbolas.

It would seem advantageous, in constructing isomagnetic charts covering the whole world or any large part of it, first to set out the data on a large globe rather than on the flat. This helps to avoid errors in the

*We have seen in §10 that every regular function f has at least two singular points; but the *a priori* probability that it has singular points of these doubly special types is zero, because they correspond to definite values of k out of an infinite continuum of possible values.

†It is not shown on the isogonic chart for 1930 published by the United States Hydrographic Office (see Terrestrial magnetism and electricity, McGraw-Hill Book Co., 1939, p. 11, or Geomagnetism, Oxford University Press, 1940, p. 97, which shows the United States isogonic chart for 1935.)

inferred isomagnetic lines due to the unavoidable distortions and variation of scale of the map-projection; it also permits full advantage to be taken of the complete connectedness of the spherical surface, without the distracting influence of boundaries such as, on a flat map, may cause unconscious errors in the outlying parts of the isomagnetic lines. An example of this, occurring on a valuable map drawn with great care, is found in Professor Bartels' well-known maps of the ionospheric current-system associated with S and L, the solar and lunar daily magnetic variations.* These maps cover the whole Earth, and the zero-line (which in the equinoctial maps, but not in the solstitial maps, is also a nodal curve) is shown as passing through the north pole. Unless it had a discontinuity of direction there (for which there is no warrant, nor any suggestion of it on other maps of the same system drawn by Professor Bartels on a different projection**), its tangent there must be tangent also to a particular meridian circle, and the line must approach and leave the pole along this meridian; hence at latitude $\pm 90°$ it cannot be inclined to the meridians, as shown on some of the maps referred to; it must also meet the upper and lower boundaries of the maps at points differing in longitude by exactly 12 hours.

After having drawn the isomagnetic lines on the globe, they can afterwards easily be transferred to a flat map with any kind of projection. In view of the great labor and cost of obtaining the data for isomagnetic charts, the additional step of plotting the data on a globe (where this is not now done) would seem well justified; the globe should have suitable meridians and parallels of longitude marked on it, clearly yet not so conspicuously as to affect the judgment in drawing the isomagnetic lines. It might even be advantageous to obscure these lines temporarily, after the data have been set out on the globe, and before drawing the isomagnetic lines. Such a globe should, I suggest, be a part of the equipment in any office responsible for constructing isomagnetic charts.

If the map-projection used for the chart is a conformal one, which preserves the angles between lines radiating from a point, in any small region, and also preserves ratios of distances within each small region, then the axial ratio of the elliptic contour-lines round a focus, and the inclination of the two parts of the nodal curve through a node, will be the same on the map as on the sphere; in particular, a circular focus or a rectangular node on the sphere will have the same property on the chart. This is the case, for example, when Mercator's projection is used, as is usual in isomagnetic charts for nautical use; but it is not the case for nonconformal charts (such as those on pp. 98-101 of Geomagnetism).

*J. Bartels, Ergeb. exact. Naturwiss., 7, 114-157, 1928; also see Terrestrial magnetism and electricity, McGraw-Hill Book Co., 1939, p. 348, and Geomagnetism, Oxford University Press, 1940, pp. 229, 263.

**See Geomagnetism, Oxford University Press, 1940, p. 696.

Imperial College of Science and Technology,
South Kensington, London, England

NOTES ON ISOMAGNETIC CHARTS: II—THE FORM AND DISPOSITION OF THE NODAL CURVES

By S. Chapman

Abstract—The form of the special isomagnetic lines which cross themselves (the nodal curves) is discussed, and the nature of the regions into which they divide the surface of the sphere. Geomagnetic illustrations of the simpler types of isomagnetic chart are cited.

§ 1. *Purpose*—In a former Note* with the same main title as the present one, I considered one aspect of the geometry of isomagnetic charts, namely, the nature of their singular points, and the form of the isomagnetic lines near these points. In the present Note other aspects of the geometry are considered, namely, the whole form and disposition of the nodal curves, and the nature of the regions into which they divide the surface of the sphere. It is hoped that this consideration of the geometry, with illustrations of some simple cases, will be of service to those who construct isomagnetic charts.

§ 2. *Ordinary and nodal curves*—In I § 7 it was shown, by considering the variation of a function f near any point on the sphere, that if the surface gradient vector of f at the point was not zero, the counter-lines of f through and near the point are, in this region, approximately straight and parallel. Such a point is called an ordinary point. A curve which is ordinary at all its points will be called an ordinary curve.

Points where the said gradient vector vanishes are called singular points, and are of two kinds, foci or nodes (or, in special cases, cusps—I § 12). At a focus f has a maximum or minimum (either principal or secondary), and the adjacent contour-lines are coaxial ellipses centered at the focus. At a node (and also at a cusp) f has a stationary value which is neither a maximum nor a minimum. The contour-line through a node consists, near the node, of two straight lines intersecting there (in general not at right-angles); the adjacent contour-lines, near the node, are hyperbolas with these straight lines as asymptotes (I §§ 8-12).

The values of f at the singular points are called singular values—focal, nodal, or cuspidal. In general they are all different. Hence there will in general be only one singular point, either a focus or a node, on a contour-line whose parameter (I § 2) is a singular value. If the singular value is focal, the focus is an isolated point on the contour, which may in addition include one or more ordinary curves. If the singular value is nodal, the contour-line must include one curve which includes the node, but is elsewhere ordinary; such a curve is called a nodal curve; in addition the contour may include one or more ordinary curves. If the singular value is cuspidal, the contour will include one cuspidal curve, and may also include one or more ordinary curves.

In special cases a nodal curve may include two or more nodes, in which case it will be called a double or multiple nodal curve; otherwise it will be called a simple nodal curve. If more than one nodal value is equal, the nodes may be on separate simple nodal curves, or some or all may lie on double or multiple nodal curves.

*This Note will be referred to as I.

Contour-lines whose parameters are not singular values are composed wholly of one or more ordinary curves.

We regard the surface of the sphere as being divided into distinct regions by any nodal (or cuspidal) curves which lie on it.

§ 3. *The fundamental contour-family*—Every regular function f (I § 3) has at least one principal or greatest maximum, and one principal or least minimum. The simplest type of contour-family corresponds to a function which has no other singular values. All its contour-lines are ordinary simple closed curves, which, as the parameter c decreases from the maximum to the minimum, expand from the maximum focus and finally contract again to the minimum focus. The corresponding contour-surface S' (I § 3) slopes steadily from the point of maximum to that of minimum level.

§ 4. *Lines of minimum descent or ascent between pairs of like foci*—Every regular contour-surface (not a sphere) has one maximum and one minimum focus; if it has more than one of either, it must also have one or more saddle-points (I § 12), which correspond to nodes of the contour-family. To prove this, consider a surface S' which has two maxima, P'_1 and P'_2. Since each is higher than all immediately adjacent points, it is necessary, in order to pass from P'_1 to P'_2, first to descend and then to ascend again. The amount of the descent, to the lowest point of the path, will depend on the path chosen; the greatest possible descent occurs on paths which go through the principal minimum of S'; these are paths of *maximum* descent. There will also be paths of *minimum descent*, which cannot be displaced, near their lowest point, without increasing the descent. Let P'_0 be the lowest point on such a path p. At P'_0 the tangent to p (and to all paths of minimum descent through P'_0) must be horizontal, and all points on these paths, near P'_0, must be above P'_0; but there must be points on S', near P'_0, which are lower than P'_0, because by hypothesis paths adjacent to p, near P'_0, which do not pass through P'_0, must descend below P'_0. Hence though the tangent plane at P'_0 must be horizontal, P'_0 is not a point of maximum or minimum level; unless it is a higher singularity of f, it is a saddle-point corresponding to a node (I § 12) of the contour-family.

Similarly we can show that there must be at least one saddle-point and node if there are two minima of S', and that the saddle-point is the summit of a path of minimum *ascent* joining the two minima of S'.

In this connection we may refer to a general theorem on the number of saddle-points and maxima and minima on a contour-surface. When the contour-surface is a simple closed surface, as we here suppose (so that its genus, in the language of geometry, is zero), and when we consider only ordinary nodes (where a curve simply crosses itself, ignoring singular points of more special character where the nodal curve has more than four lines diverging from the node) the theorem* states that

$$n = f - 2$$

where n is the number of such nodes, and f the number of foci (maxima or minima). For a fundamental family, $n = 0$, $f = 2$. For a family with three foci, $f = 3$ and then $n = 1$. Each additional focus adds one node.

§ 5. *A contour-family with three foci and one node*—(a) After the

*See Hamburger, Math. Zs., **19** (1924), who also gives references to the work of Poincaré and Bendixson on this subject. I owe the reference to this paper to my colleague L. Roth.

fundamental type of contour-family (§ 3), the next simplest is one with three foci, of which two must be of like kind; their presence requires the existence also of a node (§ 4). We shall consider the standard form of this type to be one having two maxima and one minimum; we may pass to this type from the converse by reversing the sign of the function f (I § 2).

The two maximum values of f may be denoted by $f_\wedge$, $f_{\wedge'}$, the former being the principal maximum*; let $f_\vee$ denote the minimum value of f, and f_x the nodal value. Then by §4,

$$f_\wedge > f_{\wedge'} > f_x > f_\vee$$

Let $F_\wedge$, $F_{\wedge'}$, $F_\vee$, and N be the corresponding foci and node. The nodal curve through N is simple, since there is only one node present; the curve divides the sphere into three regions, within each of which the contour-curves are ordinary. The curves whose parameters c lie between f_x and $f_\vee$ surround the focus $F_\vee$, those for which $f_\wedge > c > f_{\wedge'}$ surround $F_\wedge$, and for $f_{\wedge'} > c > f_x$ there are two sets of contour-curves (that is, two curves for each value of c): one surrounding $F_\wedge$ and one surrounding $F_{\wedge'}$. These two sets of curves lie in the two loops of the nodal curves, and $F_\vee$ lies outside the two loops. The nodal curve is transitional between the contour-lines surrounding $F_\vee$, which for each value of c ($f_x > c > f_\vee$) have one curve only, and those for greater values of c, some of which ($f_{\wedge'} > c > f_x$) include two separate closed curves (Fig. 1).

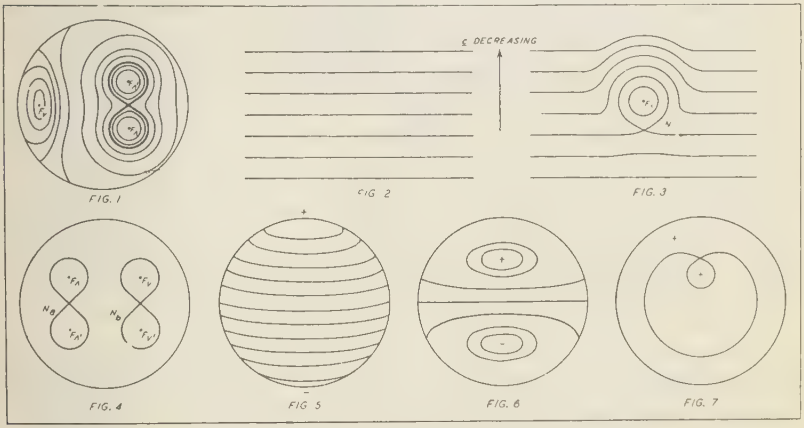


FIG. 1 FIG 2 FIG. 3 FIG. 4 FIG 5 FIG. 6 FIG. 7

(*b*) We may think of this contour-family, and its associated function f and contour-surface S', as being formed by modification of a fundamental family and its associated function and surface, having only a maximum at $F_\wedge$ and a minimum at $F_\vee$. To create the extra maximum we have to raise a hill on S', with its summit at the point corresponding to $F_{\wedge'}$. Whereas the region in which this hill is created formerly sloped steadily, and had ordinary simple contour-curves, the hill introduces a

*The suffix $\wedge$ for a maximum focus is intended to suggest a hill-top, and the suffix $\vee$ for a minimum focus likewise suggests a valley-bottom.

new limited region in which the contour-curves are closed curves round $F_{\wedge'}$, for parameters c which already have simple contour-curves round $F_{\wedge}$. The transition to the contour-lines which remain single curves is made by the nodal curve through the node N, which corresponds to the saddle-point, on S', between $F_{\wedge}$ and $F_{\wedge'}$. If the hill affects only a small region round $F_{\wedge'}$, the change in the contour-lines in this region is as shown in Figures 2, 3. In Figure 3, as we pass through N in the direction of the arrow on the left, c decreases until we reach N, but inside the loop of the nodal curve c increases in this same direction; in transverse direction outwards from N, c decreases.

(c) The three regions into which the nodal curve divides the spherical surface S may be called uniangular or biangular relative to this curve, according as they have, on their boundary, respectively, one or two of the four angles at N. The biangular region is the one surrounding $F_{\vee}$, within which the contour-curves are all simple; the uniangular regions are those within the loops of the nodal curve, and each contains one focus, $F_{\wedge}$ or $F_{\wedge'}$. We may indicate the number of regions of the sphere, and their "angularity," by the symbol $2(1)+(2)$, the numbers in parentheses indicating the angularity, and the number outside, that of the regions with this angularity. The total number of angles, namely 4, is equal to $2(1)+(2)$ interpreted in the ordinary algebraic sense.

We may also add $+$ and $-$ signs inside the parenthesis to indicate whether there is a maximum $(+)$ or a minimum $(-)$ focus in the corresponding region; the symbol for the family then becomes $2(1+)+(2-)$; for the function $-f$, these focal signs must be reversed.

(d) The nodal curve and all the contour-lines within its two loops may be regarded as substituted for the contours, in that region, of a fundamental contour-family having its minimum at $F_{\vee}$ and one maximum somewhere within the (double) region enclosed by the nodal curve. The two maxima and the partly double set of contour-lines within the nodal curve replace the single maxima and simple contour-lines of the fundamental family.

§ 6. *A contour-family with two maxima, two minima, and two nodes*—If we similarly replace the single minimum focus $F_{\vee}$ in Figure 1 by two minima, $F_{\vee}$ and $F_{\vee'}$, lying within the loops of a nodal curve through a node which we denote by N_b (to distinguish it from the original node, which we now write N_a), we obtain a family of the type sketched in Figure 4 [the Figure is drawn on the supposition that (in the notation of § 5)]

$$f_{\wedge}>f_{\wedge}>f_x>f_{x'}>f_{\vee'}>f_{\vee}$$

The two nodal curves a, b through N_a and N_b, now divide the surface into five regions, of which four are uniangular (two with respect to the node N_a, and two with respect to the node N_b) and one is biangular with respect to both nodes; hence the character-symbol of this contour-family can, as in § 5(d), be written $2(1a+)+2(1b-)+(2a,\ 2b)$, which has the algebraic sum 8, or 4 for node a and 4 for node b, corresponding to the four angles at each. It also indicates the character of the foci in the regions accessible to one or other nodal angle.

A new feature of the present family, as compared with the families considered in §§ 3, 5, is that the contour-lines in the region $(2a+2b)$, which are simple curves, cannot be "reduced," by varying c, to a point (without crossing a nodal curve and therefore passing outside their region); this

region may therefore be called *irreducible*. A region bounded by two nodal curves of different parameter is necessarily irreducible. The region corresponds to the one between two contour-lines of a fundamental family, with parameters c_a, c_b, say. Only by c increasing or decreasing outside these limits can the contour-line in this case tend to one or other principal focus—in Figure 4 this is barred by one or other of the two nodal curves.

If, as a special case, the two nodal values of f are equal ($f_{xa}=f_{xb}$), while yet the two nodal curves a, b are distinct, the irreducible region between them must be a contour-*area* (I § 4), all at the same level; otherwise there would have to be a maximum or a minimum, or both, in this region, contrary to our supposition that there are only the four given foci. The theorem of § 4 shows that if there are only two nodes there must be exactly four foci.

§ 7. *The distortional equivalence of contour-familes.*—We shall later show how we may classify more complicated contour-families, according to the number and angularity of the regions into which the sphere is divided by the nodal curves. When those features of a family are specially considered, apart from the actual location and detailed form of the lines, we shall regard two or more families as *distortionally equivalent*, if they can be made to coincide with one another, by mere displacement and deformation—that is to say, by shifting and stretching or shrinking, but without reducing any closed curve to a point, nor altering the sequence or relative order of the lines of the same family, as would happen if we made any line pass over its neighbors; hence, in particular, no contour can cross any nodal curve, so that the character of the contours in the region bounded by these curves remains constant.

As the simplest example of this, we regard all fundamental families (§ 3) as distortionally equivalent, wherever their foci are situated, and whatever their focal values. Two such contour-families are illustrated in Figures 5, 6; one is symmetrical about a diameter of the sphere, and all the contour-lines are circles in planes perpendicular to this axis, the maximum being at one end of it and the minimum at the other; in the other family, the two foci are close together, and between them the contour-lines are more crowded than elsewhere. In each Figure a maximum focus is indicated by the sign $+$, and a minimum focus by the sign $-$.

Similarly all contour-families with only one simple nodal curve, and three foci, are regarded as distortionally equivalent; the two like foci may, for definiteness, as in § 5, be taken to be maxima, by reversing the sign of f if necessary. Figure 7 shows a simple nodal curve which appears to differ from the one shown in Figure 1, in that, of its two loops, one is inside the other. But the two forms are distortionally equivalent; to convert the nodal curve in Fig. 7 into one like that of Figure 1, we need only extend the larger loop downwards, draw it round the back of the sphere, and upwards, and then shrink it to a loop above the inner loop. Conversely either loop of the nodal curve in Figure 1 can be drawn round the back of the sphere so as to enclose the other.

The character-symbol for the contour-family whose one nodal curve is as shown in Figure 7 is $2(1+)+(2-)$, just as for Figure 1 (§ 5); this identity is necessary, since the distortion defined above does not alter the angularity (or the irreducibility) of any region.

§ 8. *Contour-families with two simple nodal curves*—In § 6 a contour-

family with two nodal curves a, b, was illustrated (Fig. 4). Any such family, according to the general theorem quoted in § 4, must have four foci, but these are not necessarily two maxima or two minima—there may be three maxima and one minimum (or the converse, included in the same case if we reverse the sign of f). Moreover if there are two maxima and two minima, it is not necessary that, as in § 6, $f_{\vee} > f_{\vee'} > f_{\vee'} > f_{\vee}$; we may also have $f_{\wedge} > f_{\vee'} > f_{\wedge'} > f_{\vee}$, that is, the level of the lower maximum may be below that of the upper minimum, or the maxima and minima are *interlaced.* Hence we may expect at least three possible types of family with two simple nodal curves. Actually there appear at first sight to be several more such types, but many of these are distortionally equivalent, and they reduce, as expected, to three independent types. This is illustrated by Figures 8, 9, and 10, each of which includes more than one form of apparently different but actually equivalent arrangements of the two nodal curves.

The difference between the three types of Figures 8, 9, 10, is indicated by the corresponding character-symbols, which are as follows:

Figure 8	$2(1a+)+2(1b+)+(2a, 2b)$
Figure 9	$2(1a+)+(1b+)+(2b-)+(1b, 2a)$
Figure 10	$(1a+)+(1b-)+(2a-)+(2b+)+(1a, 1b)$

In all cases there are five regions, of which one is irreducible; the number of angles at each node is four. It is readily seen that the above character-symbols fit all the diagrams under the corresponding Figure.

In Figures 8 and 10 the character-symbol is unaltered by interchanging a and b, signifying that the two nodal curves play corresponding rôles in either family: this is not so, however, in Figure 9. The difference is connected with the fact that in Figure 8 the loops of one nodal curve contain two maxima, and those of the other contain two minima (as indicated by the + or − signs inserted in the loops); in Figure 10 each nodal curve has a maximum in one loop and a minimum in the other –but in Figure 9 one nodal curve encloses two maxima, and the other encloses one maximum and one minimum. By considering the variation of f from a focus to a node, from there to the other node, and onwards within its loops, it is easy to show that the foci in the several regions are as indicated in the Figures (and also in the above character-symbols) by the + or − signs. A reversal of f would reverse all these focal signs. With the given signs, it is evident that the nodal values (n_a, n_b, say) are ordered as follows in the three cases: Figure 8, $n_a > n_b$; Figure 9, $n_a > b_b$; Figure 10, $n_a < nb$.

§ 9. *Contour-families with one double nodal curve*—When the two nodal values n_a, n_b are equal, either they lie on two simple nodal curves, with an irreducible contour-*area* between them (§ 6), or they lie on a double nodal curve. We consider the possible varieties of such a curve. By the theorem of § 4, there are four foci, which may be discussed as in § 8; there are three possible types of family, as illustrated (with alternative forms) in Figures 11, 12, 13, which are analogous, in the kind and order of their foci, to Figures 8, 9, 10, respectively. In each case the nodal curve divides the surface into *four* regions (four are *necessary*, since there must be four foci of a family with two nodes); none of them is irreducible (the presence of such a region would require two *different* nodal curves

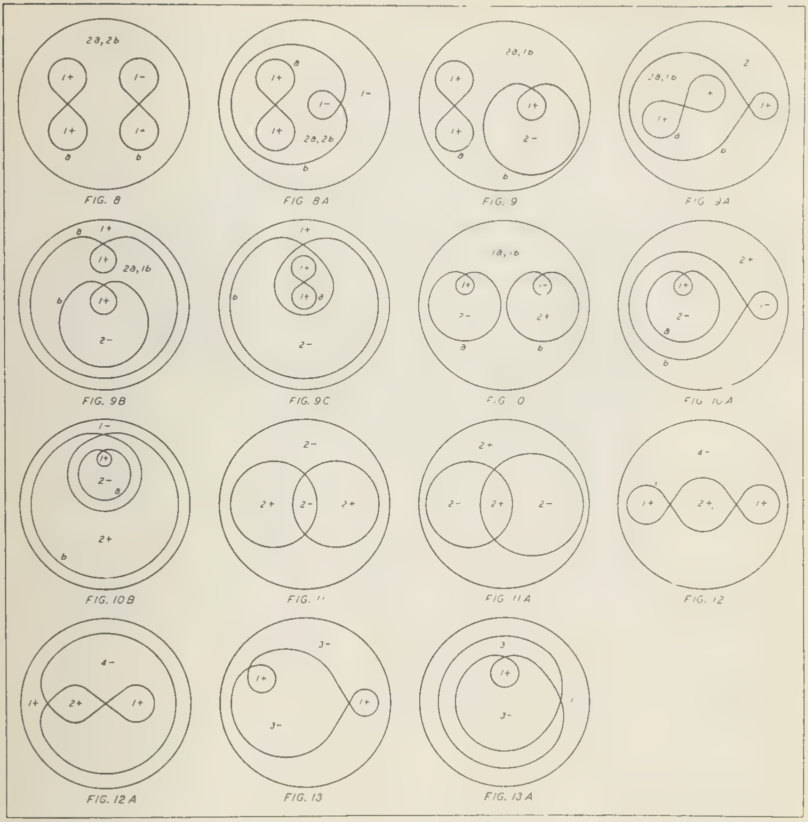


FIG. 8, FIG. 8A, FIG. 9, FIG. 9A, FIG. 9B, FIG. 9C, FIG. 10, FIG. 10A, FIG. 10B, FIG. 11, FIG. 11A, FIG. 12, FIG. 12A, FIG. 13, FIG. 13A

and values). The character-symbols for the three cases are:

Figure 11	2(2+)+2(2−)
Figure 12	2(1+)+(2+)+(4−)
Figure 13	2(1+)+2(3−)

Further more complex cases might be considered in a similar way, but I conclude by mentioning a few geomagnetic illustrations of the simple types of family here discussed.

§ 10. *Geomagnetic illustrations: (a) Fundamental contour-families* These are illustrated by the isomagnetic charts for Z and I for the field of a uniformly magnetized sphere, because these elements have only one minimum and one maximum, one at each magnetic pole. The isoclinic charts for the actual Earth's field, as illustrated in TME* (p. 12) or GM**

*This abbreviation refers to Terrestrial magnetism and electricity, edited by J. A. Fleming, McGraw-Hill Book Co., 1939.

**This abbreviation refers to Geomagnetism, by S. Chapman and J. Bartels, Oxford University Press, 1940.

(p. 100), are also of the fundamental type, though this would not be so for isoclinic charts on a larger scale, illustrating the field in finer detail.

(*b*) *Families with one simple nodal curve and three foci*—An example of such a family is given by the isomagnetic chart for the total intensity F for 1922, drawn by Ennis from data scaled by Dyson and Furner from the British Admiralty Charts, and reproduced in GM (p. 101). Its two maxima are near the magnetic poles, and its one minimum is near 20° south latitude. The node (not shown) is near 10° north in 110° east. As in all these illustrations, further singular points would of course be revealed on a chart showing finer detail.

(*c*) *Families with two simple nodal curves*—The British Admiralty isomagnetic chart for H, 1922, reproduced (in modified form) in GM (p. 99), shows four foci, namely, minima near each of the two magnetic poles, and another near 45° south in 40° east together with one maximum near 20° north in 100° east. A reversal of signs would render this an illustration of the type of family shown in Figures 9; its character-symbol (without reversal) is $2(1a-)+(1b-)+(2b+)+(1b+2a)$. The nodes and nodal curves are not shown, but the node a, conformable to this character-symbol, and belonging to the nodal curve whose loops both include minima, is near 50° south in 60° east, the other node (b) is near 8° north in 320° east. The minimum near the north pole is in the biangular region of the nodal curve b.

(*d*) *Families with one double nodal curve*—The current-diagram for S_q at the equinoxes, drawn by J. Bartels and reproduced in TME (p. 348) and GM (p. 229), is an example of such a family; it is of the general type shown in Figures 11, having two maxima and two minima, each lying in a biangular region. It is special in that its two nodes are both rectangular (I § 11); this is a consequence of the idealized symmetry of the diagram, and is not found in the less idealized partial current-diagram for the same season by A. G. McNish (TME, p. 353, or GM, p. 779).

In Bartels' corresponding current-diagram for the solstice (GM, p. 229) the nodes and nodal curves are not shown, and it is not quite certain that the two nodal values are the same; if not, this diagram would be an illustration of case (*c*) above, but of the type of Figure 8, having two maxima and two minima, not interlaced (that is, the lesser maximum exceeds the greater minimum).

(*e*) *More complicated contour-families*—The isomagnetic charts referred to above, if drawn on a larger scale so as to show finer detail, would reveal many more singular points and nodal curves. But the isoporic charts constructed by H. W. Fisk* probably afford the best examples of world isomagnetic charts, on a relatively small scale, which nevertheless show many singular points—even the simplest, that for the magnetic inclination I, has at least five foci, and therefore (§ 4) at least three nodes (not shown).

*Isopors and isoporic movements, Internat. Geod. Geophys. Union, Sect. Terr. Mag. Electr., Bull. No. 8, Stockholm Assembly, 1930, pp. 280-292 (Paris, 1931); also see TME, p. 24, and GM, pp. 115-119.

Imperial College of Science and Technology,
South Kensington, London, England

THE ELECTRICITY OF CONTINUOUS RAIN

By J. Alan Chalmers and E. W. R. Little

§ 1. *Introduction*

The measurement of the electric charge on rain is of interest from two points of view; in the first place, the precipitation-currents may be of importance in the discussion of what Wormell [see 20 of "References" at end of paper] has called "the electrical balance sheet of the Earth"; and further, the results for the charges on rain can give clues as to the mechanism involved in the acquisition of such charges and hence as to the processes at work in producing separation of charge in and below clouds.

Measurements in various parts of the world have shown that there is a positive excess of charge brought down to the Earth, more especially in rain classified as "continuous," "ordinary," or "non-stormy" (German "Landregen"). Apart from this, little has been achieved in the establishment of general results capable of providing a basis for theoretical discussion.

Investigation is made difficult by the lack of control of the experimental conditions and by their rapid fluctuation. Therefore results obtained on a particular occasion, when the conditions were exceptionally steady, are very suitable for discussion. Such results, recorded during a period of steady continuous rain from $13^{h}\,00^{m}$ on March 27 to $06^{h}\,00^{m}$ on March 28, 1939, are analyzed below. In addition to the rainfall-current, simultaneous measurements were made of the point-discharge current, which is dependent on the potential-gradient.

In any discussion on the origin of the charges on the rain and the charges giving rise to the potential-gradient, it is necessary to consider the problem of the electrical structure of the rain-cloud. Hitherto, such investigation has been confined almost entirely to storm-clouds (Cu-Nb), about which information has been obtained from investigation of the effects of lightning-flashes, and also by the results of the alti-electrograph [15]. But clouds of other types, for example, clouds in advance of a warm front, are also electrified, and it seems that the discussion of rain-charges and potential-gradients may form a first mode of attack on the problem. Since the vertical air-currents in such cases are so much less intense than in thunder-storms, it is clearly not legitimate to assume that conditions in regard to the separation of charge are at all similar.

§ 2. *Apparatus*

For the purpose of estimating the total vertical current carried to the Earth by a fall of rain, it is best to use a receiving surface which is fully exposed to the rain. This has been discussed by Chalmers and Pasquill [3]. Wilson [19] was the first to use an exposed conductor with a surface approximating to that of the Earth; his apparatus was insulated and supported in a hole in such a manner that its surface was level with the surrounding ground. He suggested that such an arrangement would give complete compensation for any effects due to splashing, but he only used the method for short periods, and not for continuous observations.

Schonland and Craib [12] and Wormell [24] also used this method for measurement of rain-charges during a few thunder-storms, but never made continuous observations.

The apparatus used in the present work consists of a wooden tray approximately one meter square, lined with zinc in such a manner as to make it water-tight, with a plug fitted to the bottom so that surplus water may be let out when desired. The tray is 12 cm deep, and is fitted with a wooden false bottom supporting a layer of earth in which grass similar to that in the neighboring fields is allowed to grow uncut. This collecting surface is mounted on four sulphur insulators, electrically heated to maintain dryness. Metal receptacles are hung from the tray in such a manner as to collect any rainwater which runs down the sides and drips off. It being impossible to place the apparatus in a field, the collector has been placed on the flat roof of the Science Laboratories at Durham, and surrounded with a "guard-ring" of similar grass of width 30 cm, separated from the collector by a gap of about 2-1/2 cm.

The collecting surface is connected by means of a lead-covered cable to one side of a one-half-microfarad condenser, the other side of which is earthed to a water-tap in the building. It was found necessary to keep the rubber insulation at the upper end of the cable warm by means of a heating coil, for otherwise a large spurious effect occurred whenever moisture condensed on the rubber. Clockwork mechanism discharges the condenser at intervals of about ten minutes through a high-sensitivity galvanometer, the deflection of which is recorded on a drum-camera. Three shunts for the galvanometer have been arranged, so that the apparatus is capable of recording charges equivalent to currents entering the ground ranging from 10^{-17} to 10^{-11} amp/cm^2. For the record here discussed, the medium range of sensitivity was used, a deflection of one mm corresponding to 1.33×10^{-8} coulomb, or an average current over the ten-minute period of 2.30×10^{-15} amp/cm^2.

Daily measurements have been made of the rate of leakage of the collecting system, showing an average loss of charge of 2.0 per cent in ten minutes. The capacity of the system is such that it may be regarded as remaining practically at earth-potential, even when charged by rainfall. It may be noted that a change in the vertical potential-gradient above the apparatus during the ten-minute period will, by altering the "bound" charge on the collector, cause an apparent current to be recorded; this effect will be balanced out when the potential-gradient returns to its normal value. A change in potential-gradient of 600 volts/meter corresponds to a current of 10^{-15} amp/cm^2. When hourly averages are taken, this effect is less, and a difference of potential-gradient of 600 volts/meter between the start and end of an hour only corresponds to an average current of 1.6×10^{-16} amp/cm^2.

A simultaneous record was made on the same photographic paper of the current discharged from an exposed point. For this purpose, a platinum point was supported, insulated by means of paraffin wax sheltered from the rain, on a pole attached to a projection above the building, so that the point was three meters above the projection and six meters above the general level of the roof. A lead-covered cable connected the point to earth through a galvanometer. It was found convenient to arrange a shunt for this galvanometer, to give different sensitivities; in the present case, the sensitivity was one mm for 5.2×10^{-7} ampere.

§ 3. *Results*

Table 1 shows the results for the different periods of about one hour during the time of rainfall; also included are results for the rainfall as taken from the record at Durham Observatory situated about one-half mile away. The times are taken from the moment when the condenser begins to charge for the last "ten-minute period" before the next hour. Six such periods are taken together (seven in one of the hours). It may be noted that the periods are not exactly ten minutes, 146 occurring in 24 hours.

The period of continuous rain here discussed was associated with a "warm front" of a depression traveling slowly northwest from Germany. The rain ceased when the front passed over Durham at about $06^{h}\ 00^{m}$ on March 28. The cloud-base was at an altitude of 250 meters and the "snow-line" on near-by hills was also about 250 meters. The clouds were of fracto-nimbus type.

The most prominent feature of the record is the marked parallelism between the point-discharge current and the rain-current during the period. The point-discharge current was negative for a total of 582 minutes and positive for two minutes. There were 74 periods when the aggregate rain-current was positive and 16 when it was negative.

This is in striking contrast to the only record of "continuous rain" reproduced by Scrase [13] when there is no obvious correlation with the point-discharge current.

TABLE 1

Time-interval March 27-28, 1939	Total rainfall per hour	Rain charge per cm² per hour	Point-discharge per hour	Average rain-current	Charge on rain	Point-discharge per hour
h m h m	*mm*	10^{-12} *coul.*	10^{-5} *coul.*	10^{-16} *amp/cm*²	*esu/cc*	*esu/cc*
12 58–13 58	0.84	−2.42	− 3.0	−6.8	−0.089	0.030
13 58–14 57	1.14	7.92	− 58.2	22.0	0.208	−0.004
14 57–15 55	1.37	10.37	− 80.4	28.8	0.227	−0.003
15 55–16 54	0.89	6.95	− 86.4	19.3	0.234	−0.003
16 54–17 53	1.50	8.46	−132.6	23.5	0.169	−0.001
17 53–18 53	1.27	8.93	−121.2	24.8	0.211	−0.002
18 53–19 52	1.40	9.54	−166.2	26.5	0.205	−0.001
19 52–20 51	0.96	5.54	− 49.8	11.5	0.110	−0.002
20 51–21 50	1.16	14.40	−277.8	40.0	0.372	−0.001
21 50–22 50	1.22	12.24	− 82.8	34.0	0.301	−0.004
22 50–23 59	0.61	3.74	−134.4	10.4	0.184	−0.001
23 59–00 59	0.43	2.99	− 4.2	8.3	0.208	−0.050
00 59–01 58	1.01	4.21	−124.8	11.7	0.127	−0.001
01 58–02 57	1.29	13.32	−244.8	37.0	0.310	−0.001
02 57–03 55	1.21	3.17	− 73.2	8.8	0.078	−0.001
03 55–04 53	1.27	6.41	−234.6	17.8	0.152	−0.001
04 53–05 52	0.86	9.11	− 22.8	25.3	0.317	−0.014
Average	1.08	7.27	−111.6	20.2	0.202	−0.003

Notes: The records for the period $21^{h}\ 50^{m}$–$22^{h}\ 50^{m}$ are incomplete. The values given for the rain-charge and the rain-current are based on a time of one hour.

Seven periods occurred between the times $22^{h}\ 50^{m}$–$23^{h}\ 59^{m}$. The value given for the rain-current is therefore reduced by a factor of 6/7.

One coulomb $= 3 \times 10^{9}$ esu.

§ 4. *Comparison with other results*

The results obtained may be compared with the results of other observations.

In particular, Scrase [13] mentions two cases in which a continuous period of rainfall shows results of similar type to those discussed here, with long periods of positive rainfall and negative potential-gradient.

The correlation of positive rain and negative potential-gradient is not a noticeable feature of most rainfall-measurements and seems to occur only with long-continued rain; various observers have found a general predominance of negative potential-gradient during rain, to be compared with the well-known predominance of positive charge on the rain. But, apart from the occasions mentioned by Scrase, the only indications of a definite inverse relationship between potential-gradient and rain-charge is found in the results of Elster and Geitel [4], who, however, found an excess of negative rain, and of Benndorf [1].

It is not easy to compare the results of this single day with other general results, since, in most cases, observers have given results for all kinds of rain taken together, or have given results for "Landregen," which is a much broader description than is covered by this particular day's record.

The results of Scrase [13] are, however, available for comparison, since he divides his observations according to the rate of rainfall. But Scrase gives results separately for positive and negative rainfall, and it is necessary to combine these before comparison. Although the present results differ from those of Scrase in giving few periods of negative rain, this is not very surprising if it is realized that the era of reception is much greater, so that if the negative drops, known to exist from the single-drop measurements, occur haphazard, it is reasonable to expect that there should be an excess more often when there are fewer drops in each measurement. In the present measurements, there are enough drops for the negative drops to average out and to be masked usually.

For rain of intensity corresponding to that in the present observations, we get Table 2.

TABLE 2

Authority	Scrase	Chalmers and Little
Rate of rainfall, mm/hr	0.6-1.8	1.08
Charge/cc, esu	0.165	0.202
Average current, amp/cm^2	1.8×10^{-15}	2.02×10^{-15}

This agreement denotes that there is not much difference between the present results and those of Scrase; differences might be expected for either of two reasons, namely, (1) the greater exposure of the present collector to rain obliquely and (2) the effect of splashing on the surface of the collector. The results suggest that neither of these factors has much effect in the case of continuous rain.

Using Gschwend's [8] results for "Landregen" in the same way, taking positive and negative rain together, we get an average charge per cc of 0.20 esu.

§ 5. *General discussion*

The observations show the coexistence of positively charged rain with negative point-discharge current, that is, with negative potential-gradient; and the times during which the rain is most heavily charged are, in general, times of greatest point-discharge and also times of heaviest rainfall.

The results could be accounted for either on the assumption that the primary process is the separation of positively charged rain from a residual negative charge in the cloud or below, or else on the assumption that the primary process is the setting up of a negative potential-gradient with the charging of the rain-drops by a secondary process. It is the purpose of this discussion to consider these two possibilities, though it is not possible to give any decision between them.

Scrase [13], in discussing similar results, preferred to consider the main process to be the separation of positively charged rain, thus leaving behind a negative charge in the cloud or below it, giving rise to a negative potential-gradient.

On the other hand, as Scrase also points out, Wilson [21] provided a theory, now supported by evidence from experiments in the laboratory by Gott [6, 7], according to which rain-drops falling in an existing potential-gradient could start with zero or negative charge and acquire a positive charge by absorption of ions; the main process must then be the production of a negative potential-gradient by some process within the cloud, and this can be achieved by a process of separation giving rise to an upper positive and lower negative charge in the cloud.

The two ways of regarding the problem are sharply distinguished in that the first requires a cloud which is negatively charged, while the second requires a bipolar cloud, the upper part of which is positively charged. Hence the potential-gradient above the cloud differs in the two cases, being positive for a negative cloud and negative for a bipolar cloud, for the potential-difference from the Earth to the ionosphere (the conducting layer in the upper atmosphere, often referred to as the Heaviside layer) can be considered to remain constant. It is, of course, possible that a cloud which is predominantly negative should have a positive upper portion, or that a cloud which is bipolar should have a negative charge greater than the positive, so that the descriptions "negative" and "bipolar" are not mutually exclusive; in what follows, the distinction between "negative" and "bipolar" clouds will be made by reference to the potential-gradient above the cloud.

The circumstances under discussion are those in which the conditions remain approximately steady and hence those in which there is not much change in the distribution of the electrical charges. Hence the total electrical charge reaching any volume must be approximately the same as that leaving it in the same time; since the equipotential surfaces can be supposed to be horizontal, it follows that the vertical current-density must be the same at all heights, and hence can be discussed from its value above the cloud, or its value inside the cloud or its value below.

From the above distinction between negative and bipolar clouds, it follows that, above a negative cloud there must be a positive current downwards, and thus there must be a positive current downwards also below and inside the cloud. Below the cloud, therefore the positive

vertical current-density due to the rainfall must be greater than the negative vertical current-density due to the point-discharge current.

On the other hand, for a bipolar cloud the vertical current is everywhere negative downwards, and hence the point-discharge current-density must exceed the rainfall current-density.

The last two paragraphs can be expressed in the form that the primary process gives a larger current than the secondary process, that is, if the rain-drop charge creates the potential-gradient, then the rain-current is greater than the point-discharge current and vice versa.

It is not possible to make a direct test, as suggested by this distinction, since that would involve the conversion of the point-discharge current from a single point into a current-density, and this can only be done by assuming the spacing of discharging points equivalent in discharging power to the one under consideration, that is, by assuming what cross-sectional area of the vertical current at a moderate height passes into the one point on which measurements are made. In general, such a conversion can only be carried out by a rough approximation such as has been used by Wormell [22] and by Whipple and Scrase [18]; Schonland and Craib [12] were able to obtain the spacing more accurately, since they used an actual tree as discharger and were fortunate in having similar trees with a fairly regular spacing; but their results are not applicable anywhere else.

There are various results obtained from other observations which support one or other of the theories, but these will not be discussed at present and we shall confine our attention to the results of the present set of observations. It is clear that any decision between the two theories must depend on how far each is able to give a quantitative as well as qualitative account of the observations. For this purpose, the average results over the whole period of 17 hours will be mainly used, but reference will also be made to hourly averages.

§ 6. *Numerical data and assumptions*

The observational data, as given in § 3, give the following averages:

Rate of rainfall, mm/hr	1.08
Rain-current, amp/cm^2	2.02×10^{-15}
Charge per cc of rain, esu	0.202 (or 6.7×10^{-11} coulomb)
Point-discharge current, amp	-3.1×10^{-7}
Height of base of cloud, meters	250

In order to make further calculations, it is necessary to assume some average size for the rain-drops; the only available measurement is that of Gschwend [8], who gives the average mass of rain-drops in "Landregen" to be 4.2×10^{-4} gm, corresponding to a radius of 4.5×10^{-2} cm. In order to use these results in conjunction with those tabulated above, the following results are obtained, by utilizing a table due to Lenard [9] for the terminal velocity of drops of various radii:

Limiting velocity, cm/sec	400
Drops striking one cm^2 per sec	7.1×10^{-2}
Charge per drop, coulomb	2.8×10^{-14} (or 8.4×10^{-5} esu)
Rain-charge in one cc of atmosphere, coulomb	5.05×10^{-18} (or 1.5×10^{-8} esu)
Area of water-surface per cc, cm^2	61

We may note, in comparison that, taking positive and negative charges together, Gschwend's [8] results give an average charge per drop in "Landregen" of 9.1×10^{-5} esu.

Another requirement for the calculations is the potential-gradient at the Earth's surface corresponding to the point-discharge current of -3.1×10^{-7} ampere from the point; if we accept the curve of Whipple and Scrase [18] to give a rough estimate, this corresponds to a potential-gradient of about -22 volts/cm. But it is probable that the point used in the present measurements has a better exposure than that at Kew, and it is in agreement with general results on the potential-gradient during "Landregen" to suggest a value of about -15 volts/cm, perhaps less.

We require also to know the resistance of the atmosphere above the cloud, so as to be able to relate the conduction-current there with the potential-difference. Gish and Sherman [5] found the total resistance of a column of air of one cm^2 cross-section from the Earth to the ionosphere to be 10^{21} ohms; it seems to be approximately correct to assume that about one-third of this resistance occurs above the level of the top of the cloud. Gish and Sherman give a value of 4×10^5 volts for the potential of the ionosphere, but Whipple [16] gives 3×10^5 volts, and this value is preferred as it is in better agreement with the values of the fine-weather current, on the average about 3×10^{-16} amp/cm^2; it may be pointed out that, in places where the fine-weather current is small, for example, at Kew, where Scrase found a value about 1×10^{-16} amp/cm^2, this is due to increased resistance in the lower part of the atmosphere and does not affect appreciably the results for the resistance higher up, or for the potential of the ionosphere.

The conductivity at the top of the cloud can be taken as about 10^{-15} reciprocal ohms per cc, so that the potential-gradient at that point and the charge above the top of the cloud can be obtained.

Any error in the figures assumed for conditions above the cloud will only cause minor alterations in the conclusions to be drawn later, and the rough estimates given are adequate.

Wilson's theory of the acquisition of charges by ionic absorption can be used to give the charge obtained by each drop falling in a given point-discharge current. According to the results of Whipple and Chalmers [17], a drop of radius a falling with a velocity V, through an ionic current of density i, for a distance h acquires a charge Q given by

$$Q = -3\pi i a^2 h / V$$

provided that Q is always small in comparison with Xa^2, X being the electrical potential-gradient.

Using the figures above, $(Q/i) = -1.19$, when measured in the same units.

§ 7. *Calculations*

If the point-discharge current-density is equal to the rain-current (2.02×10^{-15} amp/cm^2), then the point will be taking a current from an area of (120 meters)^2 approximately, that is, the spacing of points similar to the one under consideration is 120 meters.

If the spacing is greater than 120 meters, then the theory of the negative cloud is correct; if less, the theory of the bipolar cloud is to be accepted. We shall not discuss here the question as to what is likely to be

the correct spacing, but we shall make calculations of fields, potentials, and currents with various assumptions as to the spacing.

If the drops start at a height of 250 meters with zero-charge, and acquire their final charge by Wilson's process, then the spacing required to give the point-discharge current-density necessary is about 36 meters.

For any given point-discharge current, it is possible to obtain the variation of potential-gradient with height below the cloud by a theory due to Wilson [20], more applicable in this case than in the case of thunder-clouds for which it was originally put forward, giving

$$X^2 - X_0^2 = 8\pi ih/w$$

where X, X_0 are the potential-gradients at heights h and 0, i is the ionic current-density, and w is the ionic mobility, all the quantities being measured in electrostatic units. Chalmers [2] has calculated the effect on the potential-gradient, if there are small negative ions proceeding downwards from the base of the cloud, but it is difficult to imagine any process by which such ions can be produced.

For any given separation of points, the resultant vertical current can be calculated; if it is assumed that the resistance of the atmosphere above the cloud has its normal value (3.3×10^{20} ohms per cm^2), then the potential of the top of the cloud can be obtained. And if the conductivity just above the top of the cloud is 10^{-15} reciprocal ohms per cc, the potential-gradient at this point can be obtained. Table 3 gives the values of various quantities at different heights, with five different assumed separations of the discharging points. All the quantities are converted into the practical units, but there remains a conversion-factor, comprised of 4π and 9×10^{11}; this can be put in the form of $(100/9\times4\pi)=0.88$, by including factors of 10; in order to make more evident the relations between the various quantities in Table 3, this factor is retained and denoted by f.*

In the calculations, it is assumed that Wilson's theory of the acquisition of charges by ionic absorption is always correct in the form given above, whereas, in fact, it only gives the simple result when the charge is small in comparison with Xa^2, and this is not always true; it is not easy to make the necessary correction, and this has not been done in constructing Table 3; but the error is never very great.

The total charge on the drops below the cloud is found by multiplying the average charge by the height, 2.5×10^4 cm and by the concentration, 1.6×10^{-4} drops/cc.

In calculating the variation of potential-gradient with height, it is assumed that the charge carried by the drops is small compared with the ionic space-charge in the same region; this can be verified, showing that, even in Case V, the ratio is less than one-fifth. Errors introduced by neglecting the drop-charges are small.

§ 8. *Discussion of calculations and Table 3*

In Case I, the charges are separated in the cloud, and the drops bring down with them a negative charge which persists to the bottom of the cloud; in the large vertical ionic current, the drops then lose their negative charges and acquire positive charges before reaching the ground.

*The equation $\sigma = F/4\pi$ in electrostatic units becomes $\sigma = fF\times10^{-13}$ when the potential-gradient F is in volt/cm and σ is in coulomb/cm^2.

TABLE 3

Case	I	II	III	IV	V	Unit
Ionosphere						
Potential	0.3	0.3	0.3	0.3	0.3	10^6 volts
Above cloud						
Charge	−75	−22	−10	0	1.2	$10^{-13}f$ coul/cm^2
Vertical current	75↑	22↑	10↑	0	1.2↓	10^{-15} amp/cm^2
Top of cloud						
Potential-gradient	75↟	22↟	10↟	0	1.2↡	volts/cm
Potential	25	7.6	3.6	0.3	−0.1	10^6 volts
Within cloud						
Charges	$75+x$ $-172-x$	$22+y$ $-96-y$	$10+z$ $-69-z$	−33	−23	$10^{-13}f$ coul/cm^2
Base of cloud						
Potential	−2.9	−1.65	−1.20	−0.60	−0.47	10^6 volts
Potential-gradient	172↟	96↟	69↟	33↟	22↟	volts/cm
Charge/drop	−6.2	0	1.4	2.6	2.7	10^{-14} coul
Drop-current	−5↓	0	1↓	1.8↓	1.9↓	10^{-15} amp/cm^2
Ionic current	70↑	22↑	11↑	1.8↑	0.70↑	10^{-15} amp/cm^2
Below cloud						
Space-charges						
Drops	−1	0.7	1.0	1.3	1.4	$10^{-13}f$ coul/cm^2
Ions	157	81	54	18	7	$10^{-13}f$ coul/cm^2
Ground						
Charge/drop	2.8	2.8	2.8	2.8	2.8	10^{-14} coul
Drop-current	2↓	2↓	2↓	2↓	2↓	10^{-15} amp/cm^2
Ionic current	77↑	24↑	12↑	2.0↑	0.77↑	10^{-15} amp/cm^2
Potential-gradient	15↟	15↟	15↟	15↟	15↟	volts/cm
Spacing of discharging points	20	36	50	120	200	meters

In Case II, the drops have lost their negative charges within the lower part of the cloud, and reach the base of the cloud uncharged. The positive charge is then acquired below the cloud.

In Case III, the same process is so effective that the drops already have a positive charge at the base of the cloud.

In Case IV, the process of separation gives a positive charge to the drops and leaves a negative charge in the cloud; the ionic current tending to dissipate this charge is just sufficient to balance the current due to the rain.

In Case V, the current carried by the rain is greater than the ionic current and so there is a positive current downwards.

Table 3 can be put into the form of a diagram (Fig. 1), and it is at once clear that, in each case, there is a point in the lower part of the cloud where the potential-gradient is zero, and where, therefore, there can be no conduction-current of ions. Thus, at this point, the current must be carried entirely by the charged drops, or, as they will be at that height,

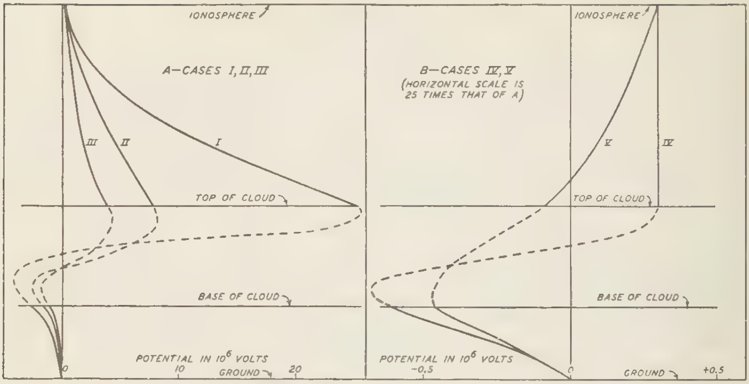


FIG. 1—VARIATION OF POTENTIAL WITH HEIGHT

snow-particles; the vertical air-currents must be too small to have much effect in this connection, and they will, in each case, be upward currents, which must therefore carry up the space-charge at the point in question, which will be negative. Hence, in Cases I, II, and III, there must be a current carried by the snow-particles at the point of zero potential-gradient, and this current must be negative downwards and very considerably greater in magnitude than the drop-currents at the base of the cloud, for the total vertical current is the same at all heights and at the base of the cloud a considerable fraction is carried by the ions. Hence it follows that the snow-particles must lose a considerable charge in falling through the lower part of the cloud; it is not certain whether snow-particles can be the agents, like water-drops, in Wilson's process, nor, if they can, what will be the relation between the charge acquired and the ionic current. If we can assume that the relation is the same as that quoted above for water-drops, then the necessary change of charge per drop would require a height of from five to six km in any of Cases I, II, or III; this is clearly impossible. If any of these cases represents the truth, it is necessary that snow-particles should be more efficient, weight for weight, in absorbing ions than water-drops. The Figure shows where there are concentrations of charge, namely at the points of greatest curvature; thus in Case IV there is a positive charge in the top of the cloud and this may also occur in Case V according to the method of drawing; at any rate, in Case V there is a positive space-charge of moving ions, both above and in the top of the cloud, so that even Case V cannot be a completely "negative" cloud.

In Case V, if the snow-particles carry no charge at the point of zero potential-gradient, the vertical current of 1.2×10^{-15} amp/cm^2 must be carried at this point by an air-current, which would have to be of magnitude 30 cm/sec, if it is assumed that the negative charge in the cloud is spread over a vertical height of 500 meters.

If Case V represents the true state of affairs, we should be able to account for the charges on the drops quantitatively, and it might be suggested that Simpson's [14] theory of breaking drops could do so. Nolan [11] found that breaking of drops gave the water a charge of 2.7×10^{-3} esu

for each cm^2 of new surface produced. The observed value of 0.202 esu cc could be accounted for if each cc of water has experienced an increase of surface-area of 73 cm^2; this can only occur if drops amalgamate without electrical effects, for the total surface-area of one cc of the drops of size assumed, is only 61 cm^2.

Results with the alti-electrograph [15] do not indicate values for the potential-gradient below the cloud as large as those suggested for Cases I, II, or III in continuous rain. The discrepancy between the alti-electrograph results and the expected fields, and the consideration of this in relation to the separation of discharging points have been discussed in connection with thunder-storms [2] and the present results show that similar conclusions apply in the case of continuous rain.

If we consider hourly mean values and assume the size of drop to remain constant, then the theory of negative cloud (Case V) would require the charge per drop and hence the charge per cc to remain constant, while the potential-gradient, and hence the point-discharge current, should be increased by an increase in the process giving rise to the separation of charge and hence by an increase in the rain-intensity. On the other hand, if the theory of the bipolar cloud (Cases I, II, and III) is correct, it would require that the charge acquired by Wilson's process should increase with the point-discharge current, so that the charge per cc should increase with point-discharge current. An increase in the rate at which the separation occurs would probably occur with increase of rain, and this should occur with an increase of potential-gradient and hence of point-discharge current; but, at the same time there would be an increase of the original negative charge on the drops, so that the effect on the charge per cc due to an increase of rain-intensity is doubtful. It can be seen that Table 1 shows points of agreement with either theory, but gives no conclusive evidence in favor of either.

Though the matter cannot be discussed in any exact detail, it seems improbable that the separation of points is as great as that required by Case V, for there are trees higher than the discharging point nearer than 200 meters.

The theory of the bipolar cloud suggests a process of separation within the cloud which can be the same as that which can account for the structure of thunder-clouds, so that one theory covers thunder-clouds and continuous rain-clouds, whereas the theory of the negative cloud requires a separate process for continuous rain-clouds.

If the theory of the bipolar cloud (Cases I, II, and III) is correct, then we may expect the drops falling within the cloud to carry negative charges, acquiring their positive charges by Wilson's process lower down. If, then, for any reason, Wilson's process is not effective, we should expect to get negative precipitation. If, in spite of what has been said above, snow-flakes do not pick up charges by Wilson's process, they would reach the Earth with the charges they had in the cloud, that is, negative charges. Now, in "quiet" snowfall, from nimbo-stratus or similar clouds, the charge is negative, as found by McClelland and Nolan [10], Gschwend [8], and Chalmers and Pasquill [3], while the potential-gradient is also negative. But, if this explanation, on the basis of the bipolar cloud-theory, is adopted, the problem remains as to how the snow-particles in the cloud lose charge.

§ 9. *Conclusion*

The discussion has shown that either the theory of the negative cloud (Case V) or the theory of the bipolar cloud (Cases I, II, or III), or else the intermediate case (Case IV) can account for a number of the observed results, while leaving some not accounted for. It seems impossible at the present stage to decide between the two theories, some lines of argument favoring one and others the other theory.

If the bipolar cloud-theory is correct, then the alti-electrograph results underestimate the fields beneath the clouds, and fresh measurements of these, such as have been projected by workers at Kew Observatory, would provide valuable evidence.

Valuable evidence would also be obtained if it were possible to make measurements similar to these here described, but using a tree of a plantation as the discharging point, so that the separation of discharging points would be known.

The measurement of rain-currents at high altitudes would eliminate any effects in the lowest regions of the atmosphere and so determine the sign of the drop-charge at a point above the Earth's surface.

It is a pleasure to thank Dr. F. J. W. Whipple for helpful advice during the preparation of the paper.

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References

[1] H. Benndorf, Wien, SitzBer. Ak. Wiss., **119**, 89-100 (1910).
[2] J. A. Chalmers, Q. J. R. Met. Soc., **65**, 237-243 (1939).
[3] J. A. Chalmers and F. Pasquill, Proc. Phys. Soc., **50**, 1-16 (1938).
[4] J. Elster and H. Geitel, Met. Zs., **5**, 95-100 (1888).
[5] O. H. Gish and K. L. Sherman, Nation. Geog. Soc., Contrib. Tech. Papers, Stratosphere Ser., No. 2, 94-116 (1936).
[6] J. P. Gott, Proc. R. Soc., A, **142**, 248-268 (1933).
[7] J. P. Gott, Proc. R. Soc., A, **151**, 665-684 (1935).
[8] P. Gschwend, Beilage zum Jahresbericht der kantonalen Lehranstalt in Sarnen pro 1921/22, 55 pp. (1922)
[9] P. Lenard, Met. Zs., **21**, 249-262 (1904).
[10] J. A. McClelland and J. J. Nolan, Proc. R. Irish Acad., **30**, 61-71 (1912).
[11] J. J. Nolan, Proc. R. Soc., A, **90**, 531-543 (1914).
[12] B. F. J. Schonland and J. Craib, Proc. R. Soc., A, **114**, 229-243 (1927).
[13] F. J. Scrase, London, Met. Office, Geophys. Mem., No. 75, 20 pp. (1938).
[14] G. C. Simpson, Phil. Trans. R. Soc., **209**, 379-413 (1909).
[15] G. C. Simpson and F. J. Scrase, Proc. R. Soc., A, **161**, 309-352 (1937).
[16] F. J. W. Whipple, Trans. Faraday Soc., **32**, 1203-1209 (1936).
[17] F. J. W. Whipple and J. A. Chalmers, not yet published (1940).
[18] F. J. W. Whipple and F. J. Scrase, London, Met. Office, Geophys. Mem., No. 68, 20 pp. (1936).
[19] C. T. R. Wilson, Proc. R. Soc., A, **92**, 555-574 (1916).
[20] C. T. R. Wilson, Proc. Phys. Soc., **37**, 32*D*-37*D* (1925).
[21] C. T. R. Wilson, J. Frank. Inst., **208**, 1-12 (1929).
[22] T. W. Wormell, Proc. R. Soc., A, **115**, 443-455 (1927).
[23] T. W. Wormell, Proc. R. Soc., A, **127**, 567-590 (1930).
[24] T. W. Wormell, Phil. Trans. R. Soc., **238**, 249-303 (1939).

Durham Colleges, University of Durham (J. A. C.).
Hatfield College (E. W. R. L.),
Durham, England

A VALUABLE NEW BOOK ON GEOPHYSICS

By E. H. Vestine

In any science the virtue of a great work is best perceived after it has aged under the purifying influence of time. When a useful collective volume appears in a science laboring without the help of a systematic treatise, its most certain immediate virtue is its organization of scattered material. The work that achieves much more is rare. Its value is then notably enhanced and we may sense a latent promise of many future benefits and expect it to mean fresh inspiration and impetus in the science. As one of this type we are inclined to welcome the important new book "Geomagnetism," by Sydney Chapman and Julius Bartels, published in April, 1940, at Oxford [Vol. I, "Geomagnetic and related phenomena" (xxviii+542 pages) and Vol. II, "Analysis and physical interpretation of the phenomena" (x+507 pages+77 tabular pages), with a total of 1126 pages and 379 illustrations].

This work is the first systematic treatise on geomagnetism forthcoming in three and one-half centuries. Until a year ago the only available works serving some of the purposes of a treatise were a few articles in encyclopedias, dictionaries, and handbooks. The situation in geomagnetism was vastly improved last year with the appearance, as Volume VIII in the series Physics of the Earth, of "Terrestrial magnetism and electricity," edited by J. A. Fleming and written by 14 eminent contributors. Some of the articles of that volume are probably the most authoritative yet to appear in English. However, the sections on geomagnetism in some respects are written "to give the reader, presumably a scientist but not a specialist in the subject, an idea of its present status together with a forward-looking summary of its outstanding problems." Parts of this volume are therefore appropriately written more for the general reader than for the specialist, although it actually provides much of great value to the specialist. In this connection the variety in the viewpoints of the different authors is also of marked benefit. The new book "Geomagnetism" generously fills many additional and more detailed needs of the serious student and investigator in the subject. It is the only fairly exhaustive systematic treatise published in this field since the famous "De Magnete" of Gilbert in 1600, with which it may some day rank as an important historical event in the discussion of geomagnetism. In conjunction with its antecedent, "Terrestrial magnetism and electricity," it might well mark the beginning of a new era in the science.

The work already has something of a history of its own. We are told its inception was in 1927, when Chapman prepared an essay awarded the Adams prize in 1929. Since 1929 the effort was pursued with the collaboration of Bartels. The task was a formidable one because they could not adopt the usual convenient practice of borrowing, revising, and reorganizing material from other suitable collective works. The latter were practically non-existent, and the companion volume "Terrestrial magnetism and electricity" did not appear sufficiently early to lend material aid. As the authors put it: "In the thousand pages of this book we have tried to collect and set in order the main facts and results of geomagnetism, based on perhaps a hundred thousand pages of printed matter (observations and discussions)." Finally the present European war

introduced added difficulties in preparation and printing, so that much extra credit is due the authors and publishers for providing the printed volumes during a time of stress.

It would be difficult to find two authors better qualified for preparing a treatise on geomagnetism. They are two of the most outstanding authorities in this field, and many of the investigations properly belonging in a treatise were actually the original work of the writers. Sydney Chapman is Professor of Mathematics at the Imperial College of Science and Technology, London, and Julius Bartels is Professor of Geophysics, University of Berlin, and Director of the Geophysical Institute, Potsdam. Both are research associates of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. These men have made numerous contributions to the science during past decades. This long experience has thus richly endowed them with critical power and insight admirably adapted for selecting and organizing material for an authoritative work.

A preliminary statement of purpose and a tempting glimpse of the content of "Geomagnetism" is afforded by a note on the cover-announcement:

"The magnetism of the Earth, its long-continued slow 'secular' change, and its more rapid periodic and irregular changes, form a group of phenomena of great intrinsic interest, which are linked also with important practical affairs -navigation by sea and air, surveying in mines and on the surface, prospecting for minerals and oil, and communication by telegraph and radio. They provide avenues of research into the Earth's interior, into the ionosphere, and into the changes that occur in the Sun's atmosphere. They are linked moreover with cosmic-ray phenomena and with the northern lights (the aurora polaris).

"For these reasons recent years have seen a growth of interest in the subject, but the lack of a modern treatise has been an obstacle to those wishing to acquaint themselves with the present state of knowledge of geomagnetism. This book aims at filling this gap. The first volume describes the main facts about geomagnetism, and also (more briefly) the facts about some related subjects the Sun and the Moon, earth-currents, the aurora, and the upper atmosphere. The second volume discusses the facts, showing how they have been studied mathematically and statistically, and with what results. It also describes the physical theories which attempt to explain the facts; but much more theoretical work needs to be done before we can claim to understand the phenomena of geomagnetism. The facts and their discussion are illustrated graphically, wherever possible, by a large number of diagrams and plates."

Book I (542 pages, 15 chapters, 28-page table of contents of Books I and II and remarks, with 34 plates and 255 diagrams) contains a wealth of descriptive information about geomagnetic and related phenomena. It gives an account of the observed facts of geomagnetism and the methods by which they are found and recorded. This constitutes Part 1 of the work. Book II (508 pages, 10-page table of contents of Book II with 4 plates and 86 diagrams) comprises Part 2 (156 pages) showing how the data described in Part 1 are analyzed and synthesized preparatory to their discussion in Part 3 (199 pages) in terms of physical causes. Appended in Part 3 are 39 pages of historical notes, 70 pages of bibliography, 77 pages of tables, a 9-page author index, and a 32-page subject index.

The arrangement by chapters is as follows, the letters *C* and *B* denoting sections mainly due to Chapman and Bartels, respectively:

Book I, Part 1: The observed phenomena of geomagnetism

(I) General principles (28 pages, *C*)
(II) Magnetic observations (67 pages, *CB*)
(III) The Earth's main field and its secular variation (41 pages, *C*)
(IV) Magnetism and geology: Magnetic prospecting (22 pages, *B*)
(V) Solar and lunar data (35 pages, *C*)
(VI) A general review of the transient magnetic variations (20 pages, *C*)
(VII) The solar daily variation on quiet days, S_q (30 pages, *C*)
(VIII) The lunar daily magnetic variation L (28 pages, *C*)
(IX) The morphology of magnetic disturbance (66 pages, *C*)
(X) Bays, pulsations, and minor disturbances (17 pages, *B*)
(XI) Magnetic disturbance: Statistics and solar relationships (41 pages, *C*)
(XII) The 27-day recurrence-tendency in magnetic conditions (21 pages, *C*)
(XIII) Earth-currents (32 pages, *B*)
(XIV) The aurora polaris (38 pages, *B*)
(XV) The Earth's atmosphere (56 pages, *C*)

Book II, Part 2: The analysis and synthesis of geomagnetic data

(XVI) Periodicities and harmonic analysis in geophysics (61 pages, *B*)
(XVII) Spherical harmonic analysis in geophysics (33 pages, *B*)
(XVIII) The spherical harmonic analysis of the main field (20 pages, *B*)
(XIX) The variability of the harmonic coefficients for the solar and lunar daily variations (15 pages, *B*)
(XX) The spherical harmonic analysis of the magnetic variations (17 pages, *C*)

Book II, Part 3: Physical theories of geomagnetic phenomena

(XXI) Theories of the main field and its secular variation (10 pages, *B*)
(XXII) Electromagnetic induction within the Earth (39 pages, *C*)
(XXIII) Theories of the solar and lunar daily magnetic variations, S_q and L, (49 pages, *C*)
(XXIV) Corpuscular emissions from the Sun, and geomagnetic disturbance (51 pages, *C*)
(XXV) Theories of magnetic storms and aurorae (48 pages, *C*)
(XXVI) Historical notes (40 pages, *C*)
Bibliography (70 pages)

It is perhaps of interest here to give some brief indication of the arrangement of the material in a typical chapter. For this purpose we list below the topics dealt with in a chapter taken from Part 2, namely, that concerning the analysis and synthesis of data.

Chapter XVI, Periodicities and harmonic analysis in geophysics

(1) Periodic and non-periodic functions
(2) The non-cyclic variation
(3) The choice of days

(4) The effect of curvature
(5) Elimination of the non-periodic part
(6) Sine-waves: Fourier series
(7) Orthogonality
(8) Approximation to a function by a finite trigonometrical series
(9) Approximation to a function by a finite series of any orthogonal functions
(10) Bessel's inequality
(11) Orthogonal polynomials: Legendre functions
(12) Harmonic analysis of a set of equidistant values of a function
(13) The connexion between harmonic analysis and correlation
(14) The relation between the Fourier series for a continuous function and the series obtained from equidistant values
(15) Corrections for non-cyclic variations
(16) Gibb's phenomenon and the convergence of the Fourier series
(17) The influence of smoothing
(18) The harmonic dial
(19) Numerical harmonic analysis
(20) Mechanical and optical harmonic analysers
(21) Graphical harmonic analysis: Physical analogies
(22) The theory of errors
(23) The asymptotic solution for the random walk
(24) The random walk with unit-displacements
(25) The harmonic components of a random set of numbers
(26) Effects of observational errors on harmonic coefficients
(27) Random series and series with conservation
(28) Conservation in magnetic character-figures, sunspots, and mortality data
(29) Statistical test for periodicities: The persistence curve
(30) Persistence in relation to the periodogram
(31) The summation-dial
(32) The generalized harmonic dial
(33) Example: The 27-day recurrence-phenomenon
(34) Example: The annual variation of magnetic activity
(35) Example: The semi-annual persistent wave in magnetic character-figures
(36) Concluding remarks

The foregoing rough scheme tends to indicate the scope of treatment in individual chapters. We next discuss the contents in more general terms.

Chapter I gives a short outline of some simple basic principles of electromagnetism, required most frequently in reading the remainder of the treatise. The treatment is mathematical, but does not aim to provide the foundation to meet the somewhat heavy demands made on the reader in later sections of the book.

In Chapter II-*A* are described the principles and organization ot measurements, their accuracy and methods, absolute instruments and magnetographs, surveys, observatories, magnetic data, and international cooperations in measurement. Some details of magnetic measurements in II-*B* give the classical solutions of problems relating to the fields of magnets, dipoles, their deflections and oscillations, and changes with time. An admirable feature which should carry much appeal to magneticians is the inclusion of sections such as Schmidt's very simple and ele-

gant exposition of the general theory of variometers [a misprint in formula (67) is here noted]. This chapter, the longest in the book, conveniently collects information and formulas frequently required by observers. The chapter closes with a forward-looking account of radical departures in methods of measurement of magnetic fields.

It is remarkable to note how little this account on instruments overlaps that in the recent book "Terrestrial magnetism and electricity." The account in "Geomagnetism" tells more clearly why the instruments function in the way they do, and gives more theory, than does "Terrestrial magnetism and electricity," but the latter is more replete in descriptions of a larger assortment of instruments. Although the purposes of a general treatise are well served by the account on measurements in "Geomagnetism," many will find the accounts (in either book) somewhat inadequate; there is room for a separate detailed treatise on magnetic instruments and the techniques developed for their use.

In Chapter III the writers lucidly introduce us to the two most dominating features of geomagnetism—the main field and its secular variation. Many charts show the results of their measurement. Chapter IV gives a concise introduction to the use of magnetic measurements in geophysical prospecting for oil and minerals, well suited to a student approaching this application for the first time. There is only brief reference to instruments and students will find additional information in "Terrestrial magnetism and electricity."

Chapter V gives a terse account of assorted facts respecting the Sun and Moon, the unity of exposition preserved by their interest to geomagnetism. Here the worker on the transient variations of geomagnetism will find much use for the convenient selection of facts formerly scattered throughout the literature.

Chapter VI follows logically with a general description of the transient magnetic variations—the solar daily variation, S, the lunar daily variation, L, and magnetic disturbance, D, as they appear together and, later, in Chapters VII, VIII, and IX these variations are described in turn as they appear when separated from each other. Their variability with time, according to year, season, magnetic activity, and with latitude is explained. Here there is as yet no detailed discussion of the cause of S, L, and D beyond the representations of their fields by current-systems within the atmosphere. Chapter X briefly describes minor disturbances of the Earth's field as yet little studied.

In Chapter XI are considered magnetic disturbances from a statistical point of view (in considerable detail) in relation to statistical features of solar activity. The treatment is amplified in Chapter XII dealing especially with the 27-day recurrence-tendency in magnetic conditions.

In Chapter XIII appears a brief summary of the principles and results of earth-current measurements. In addition to the results of modern work it includes a fascinating account of Faraday's early researches on the currents induced in moving water.

Chapter XIV includes descriptions of auroras, their variegated forms, colors, heights, spectra, geographical distribution, incidence with magnetic disturbance, and the information they afford respecting the upper atmosphere. A few interesting historical comments are also included and the chapter closes with a brief reference to relations between cosmic rays and terrestrial magnetism (the appearance of "terrestrial magnetism" here instead of "geomagnetism" is a rare instance in which the authors use the older term).

Chapter XV, on the Earth's atmosphere (particularly the upper atmosphere), is one of the highly informative sections of the treatise. We find here a very clear and concise treatment of its composition, pressure-density-temperature relationships, motions, and learn of the production of its ionized layers and their behavior in the upper atmosphere. This modern critical account will also be widely welcomed by those interested in radio transmission and meteorology.

Part II deals with the analysis and synthesis of the data described in Book I. It would perhaps be fair to say that Chapter XVI is written for the specialist in statistics and that it is not a bold attempt to make a statistician of the reader in 61 pages. There is much here for one who wishes to acquaint himself with the pitfalls to avoid, and the required modifications in his technique should he wish to work in geophysics. Even so, the enforced brevity leads at times to inadequate statements of the problems introduced and sketchy and disjointed developments, although the student may eventually grasp the meaning, after sufficient groping. There is also some evidence in the presentation of a desire to develop the subject from two conflicting points of view, namely, that of the mathematician and that of the man who wishes to handle physical counterparts. In the reviewer's opinion this is the only section of the book in which one might wish some improvements in exposition. On the other hand the value of the material so briefly presented cannot be too greatly stressed. For the first time a collection has been made of present methods and processes best adapted to the analysis of certain types of geophysical data. The methods described for Fourier analysis are admirable and based on much practical experience; we find here the best present-day treatment of geomagnetic applications of Fourier analysis. We learn also of correlation-surfaces, of the harmonic components of random sets of numbers, of the all-important feature of conservation in most geophysical data (for example, that in a sequence of 1024 days yielding daily sunspot-numbers the number of independent daily values estimated is not more than 3.1). We also find described some treatments of persistence, quasi-persistence, and helpful devices such as harmonic dials. The material of this important chapter has many original features, and may be profitably read by many writers conscious of the danger of faulty statistical treatments of problems in geophysics and in other fields.

In Chapter XVII the principles of spherical harmonic analysis are explained. This article has no peer as a summary describing the features best suited to geophysics. Chapter XVIII contains a comparison of the results of various spherical harmonic analyses of the main field. Various charts show how closely the main field may be represented by hypothetical centered and eccentric dipoles within the Earth.

The writers discuss the variability of the harmonic coefficients for the solar and lunar daily variations in Chapter XIX, providing thereby useful illustrations of the statistical techniques of Chapter XVI. Chapter XX includes the results of spherical harmonic analyses of the solar and lunar daily variations in convenient form. The coefficients of spherical harmonic terms given in various papers have been recomputed in terms of the partially normalized harmonics of Schmidt, so that intercomparisons of results are facilitated.

Part 3 deals with the physical theories which attempt to explain the geomagnetic phenomena described and analyzed in Parts 1 and 2. Many of the physical theories of geomagnetism are still in a state of flux, so

that Part 3, in one or two instances, is admittedly highly speculative and may in future prove to lack some of the enduring character of the material in Parts 1 and 2. A useful feature is provided by the mention of earlier theories now discarded. This section perhaps best fulfills the requirements of a systematic treatise. Workers in geomagnetism will value the treatment highly because of the careful assessment of the present status of our understanding of geomagnetism in terms of a conservative and guarded critical discussion.

Chapter XXI quite properly devotes only ten pages to the unexplained presence of the Earth's main field. A large number of theories are mentioned and dismissed. In Chapter XXII the results of studies of electromagnetic induction within the Earth are collected, organized, and authoritatively discussed. Tentative information is given respecting the Earth's internal electric conductivity and permeability. A valuable mathematical memoir is presented on current-induction by varying magnetic fields in regions bounded by concentric spheres.

In Chapter XXIII a dynamo-theory is outlined for the solar and lunar daily variations, and the diamagnetic and drift-current theories are criticized. Chapters XXIV and XXV deal with attempts to explain magnetic disturbance and aurora on the basis of radiations emitted by the Sun. The theories are as yet but rudimentary, and the authors sketch lines along which future progress may perhaps be made.

The book closes with an interesting short account of the history of geomagnetism. The procedure of placing this section at the end instead of the beginning of the treatise seems curious. It appears to have been included as an afterthought. On the other hand students will probably read it more appreciatively at the end of the book.

A most valuable appended feature is the 70-page bibliography. It usefully supplements the recent excellent and extensive bibliography given by Harradon in the book "Terrestrial magnetism and electricity." The list also includes a few older references not in Harradon's list, and in addition contains the bibliography since the preparation of the latter. It serves the immediate purpose of providing numbered references appropriate to each chapter in the book. This gives a more detailed classification into 36 major sections according to subject matter (25 classified by numbers and headings of chapters) than does the bibliography of Harradon. There are general lists under the headings classical works, more recent works and handbook articles, charts and tables, journals, bibliographies and abstracts, publications of observatories and institutes, international organizations and data, and expeditions. The classification by chapters is further subdivided into unnumbered subsections indicated by increasing the spacing between the lines from one to one and one-half lines (it would have been better if a space of two lines had been left blank because this convenient subclassification may not be noticed by some readers). In Harradon's bibliography the arrangement is alphabetical so that a search for a known reference is easily made. In the new bibliography one can find a reference almost as easily provided one knows something of its subject matter. Having located the appropriate section corresponding to subject matter the reference can be readily found since the sections themselves are short. Although the authors do not say so, it is obvious that they have usually tried to place the classical or most important reference first in each major section (and it should be noted that this has been attempted also in each subsection). At any rate the arrangement gives a preferred order for reading the references for the stu-

dent approaching a subject for the first time. Use is also made of cross-references. The arrangement is on the whole highly successful. This is not always true, for example, one might expect to find the paper by Walker on "The diurnal variation of terrestrial magnetism" under the major section heading "The solar daily variation on quiet days," but actually finds it in the section "The spherical harmonic analysis of the magnetic variations." This reference is found at once under "diurnal variation" in Harradon's bibliography classified alphabetically within the section according to author, but there is nothing to indicate how important the paper is likely to be.

Valuable tables list magnetic observatories, their positions and years of operation, and the earliest and latest annual means of geomagnetic elements available at this time to the authors. A few tables for use in spherical harmonic analysis are supplied. There are lists also of data on magnetic activity, sunspots, international quiet and disturbed days from 1884 to 1937, and finally the daily relative sunspot-numbers and magnetic character-figures from 1890 to 1937. The index shows painstaking care according to subjects and author.

On the whole the book achieves great clarity in its exposition. Some parts are so beautifully written that one stops in unconscious admiration of the style, which is terse and graphic (see quotation above). Enforced brevity is entailed through the attempt to cover so wide a field in so restricted a space. Thus considerable demands are made upon past experience and training of the reader, particularly if this training has not been sufficiently broad. It is a treatise and not a text-book, and many postgraduate students will find themselves best able to read the book under some measure of supervision. Many will wish to read the geomagnetic part of the recent book "Terrestrial magnetism and electricity" before proceeding to the present more difficult treatment. Those better equipped are warned that the chapters ascribed mainly to the senior author are written in a style which impels the reader onwards so quickly that some significance may be missed. The other author writes in what is to him a foreign language and there may be sometimes a tendency to find significant facts hidden among some of the details or to find some sections apparently more difficult at first than they really are. A different point of view characterizes each writer's approach to the problems of geomagnetism, although they arrive at the same result. The two writers working together thus achieve a balance contributing much that is commendable. The well-organized and scholarly treatment shown throughout both volumes has ensured a readable and successful treatise.

Finally, it may be mentioned that many sections of the book will prove valuable in other branches of geophysics, physics, and to some extent also in engineering (for example, radio communications). Such features as the statistical techniques developed merit more widespread general application in other fields. The book contains much that is new and much that may have been forgotten.

The printing is of high quality, with few misprints; there are about 420 words to the page, and the paper surface is pleasing.

The writers are to be warmly congratulated for a very notable achievement in their field.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE IONOSPHERE AT WATHEROO, WESTERN AUSTRALIA, JANUARY TO JUNE, 1940

By W. C. Parkinson and L. S. Prior

This report is a continuation of those already published in this Journal[1] and gives monthly mean hourly values of the heights and penetration-frequencies of the ionospheric regions as obtained from the automatic multifrequency ionospheric recording apparatus.

Commencing with January, 1940, some desirable changes were made in the scaling of the heights of the layers. Besides the minimum virtual height, the actual heights of maximum electron-density, uncorrected for presence of lower layers, are now scaled, using the method described by Booker and Seaton.[2]

Table 1 gives the mean hourly values of the actual heights of maximum electron-density (h^{max}) and the minimum virtual heights (h^{min}) for both the F_1- and F_2-regions, also the penetration-frequencies for the E-, F_1-, and F_2-regions and the minimum penetration-frequency recorded

Table 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, January to June, 1940*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				January, 1940				
00			346	258			6.03	
01			346	251			5.38	
02			340	263			4.67	
03			347	267			4.05	
04			351	275	0.74		3.75	
05			342	285	1.09		3.65	
06	270	248	318	269	2.06	3.47	4.76	0.64
07	258	235	325	306	2.68	4.10	5.83	0.70
08	240	220	347	346	3.13	4.57	6.55	0.79
09	232	220	358	356	3.42	4.76	7.02	0.87
10	223	210	363	353	3.55	4.91	7.46	0.87
11	221	207	385	350	3.63	4.97	7.75	0.90
12	207	197	373	353	3.69	4.98	8.17	0.91
13	230	220	363	339	3.62	5.00	8.54	0.98
14	222	213	344	318	3.59	4.93	8.54	0.92
15	220	208	338	314	3.50	4.80	8.16	0.87
16	231	216	333	306	3.32	4.62	7.63	0.81
17	242	224	324	290	2.88	4.31	7.22	0.72
18	250	234	326	258	2.27	3.75	6.78	0.65
19			332	260	1.51		6.66	0.62
20			346	256	0.93		6.86	0.52
21			361	268			6.69	
22			366	274			6.55	
23			363	273			6.32	

[1] Terr. Mag., **44**, 199-204, 341-343 (1939), and **45**, 45-47, 169-172 (1940).

[2] Phys. Rev., **57**, 87-94 (1940).

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, January to June, 1940*—Continued

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_{E}	$f^{\circ}_{F_1}$	$f^{\circ}_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				February, 1940				
00			356	281			5.25	
01			346	266			5.08	
02			335	264			4.82	
03			342	261			4.34	
04			338	257			3.99	
05			345	270	0.71		3.78	0.50
06			300	261	1.75		4.56	0.55
07	242	232	297	279	2.44	3.86	5.63	0.65
08	236	219	323	311	2.94	4.50	6.36	0.75
09	227	216	330	327	3.25	4.69	7.02	0.75
10	217	209	352	334	3.48	4.88	7.43	0.80
11	204	204	357	332	3.58	4.94	7.84	0.82
12	212	206	354	334	3.63	5.00	8.12	0.84
13	210	205	347	342	3.63	5.02	8.18	0.83
14	220	213	348	330	3.56	4.91	8.33	0.80
15	224	212	349	318	3.48	4.84	8.30	0.79
16	231	216	329	301	3.22	4.61	7.98	0.74
17	240	228	328	290	2.82	4.20	7.65	0.66
18	243	237	316	254	2.20	3.47	7.50	0.59
19			313	241	1.31		7.23	0.53
20			325	238	0.82		6.74	0.51
21			343	250			5.95	
22			360	272			5.54	
23			366	278			5.35	
				March, 1940				
00			367	272			5.10	
01			356	270			4.95	
02			355	268			4.80	
03			345	261			4.50	
04			339	258			4.20	
05			349	264	0.70		3.83	
06			313	263	1.35		4.43	
07	250	245	287	247	2.29	3.57	6.29	0.67
08	236	228	285	277	2.84	4.19	7.25	0.77
09	232	225	302	281	3.19	4.48	7.85	0.85
10	229	217	328	298	3.42	4.95	8.33	0.92
11	231	211	343	310	3.53	5.14	8.91	0.92
12	240	221	344	313	3.64	5.17	9.32	1.02
13	235	226	342	312	3.57	5.16	9.63	0.96
14	240	227	347	315	3.51	5.04	9.90	0.89
15	245	228	339	312	3.34	4.89	9.79	0.96
16	245	233	327	293	3.06	4.54	9.53	0.80
17	246	239	323	263	2.61	3.98	9.28	0.71
18			313	246	1.87		8.73	0.61
19			332	237	0.88		7.78	0.52
20			340	238			6.96	
21			347	247			6.06	
22			359	261			5.61	
23			365	266			5.26	

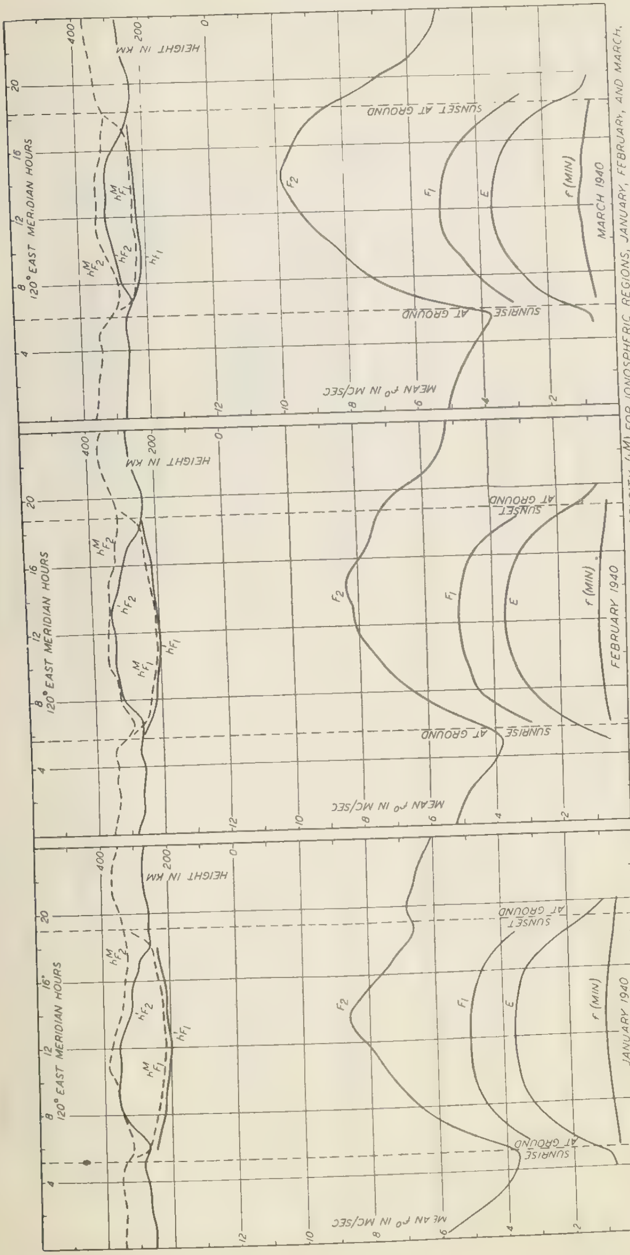


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, JANUARY, FEBRUARY, AND MARCH, 1940, WATHEROO, WESTERN AUSTRALIA

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, January to June, 1940*—Continued

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_{E}	$f^{\circ}_{F_1}$	$f^{\circ}_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				April, 1940				
00			346	258			4.72	
01			344	259			4.56	
02			345	264			4.54	
03			320	251			4.55	
04			316	239			4.03	
05			337	254	0.62		3.76	0.50
06			319	251	0.89		3.89	0.50
07			276	233	2.04		6.73	0.63
08	235	229	278	240	2.68	3.94	8.67	0.76
09	228	220	293	250	3.02	4.42	9.54	0.74
10	226	216	302	258	3.18	4.73	10.17	0.82
11	222	211	316	269	3.35	4.86	10.39	0.83
12	220	208	329	278	3.40	4.91	10.48	0.87
13	234	215	333	280	3.44	4.93	10.84	0.88
14	240	226	333	276	3.36	4.87	11.16	0.82
15	238	226	320	261	3.12	4.64	11.17	0.80
16	240	232	314	247	2.77	4.06	10.83	0.73
17			307	230	2.14		10.21	0.65
18			306	219	1.06		9.10	0.52
19			316	221	0.75		7.24	0.51
20			326	233			6.13	
21			329	242			5.60	
22			339	245			5.10	
23			344	259			4.89	
				May, 1940				
00			325	260			3.43	
01			324	262			3.55	
02			314	254			3.63	
03			303	247			3.81	
04			290	238			3.75	
05			293	230	0.71		3.27	0.52
06			289	232	0.84		3.00	0.51
07			268	228	1.85		5.26	0.59
08	230	(230)	267	228	2.47	(3.60)	7.22	0.74
09	233	229	276	242	2.93	4.09	8.26	0.77
10	232	223	283	252	3.13	4.50	8.83	0.83
11	228	222	289	254	3.26	4.63	9.29	0.81
12	227	217	306	266	3.29	4.76	9.03	0.82
13	233	225	308	271	3.27	4.70	9.34	0.78
14	237	224	306	263	3.15	4.52	9.66	0.78
15	234	230	299	251	2.95	4.23	9.87	0.73
16	225	225	288	234	2.50	3.55	9.16	0.70
17			281	222	1.83		8.35	0.69
18			279	215	1.05		6.45	0.59
19			296	227	0.80		4.44	0.55
20			305	238			3.62	
21			313	249			3.28	
22			326	258			3.23	
23			328	261			3.33	

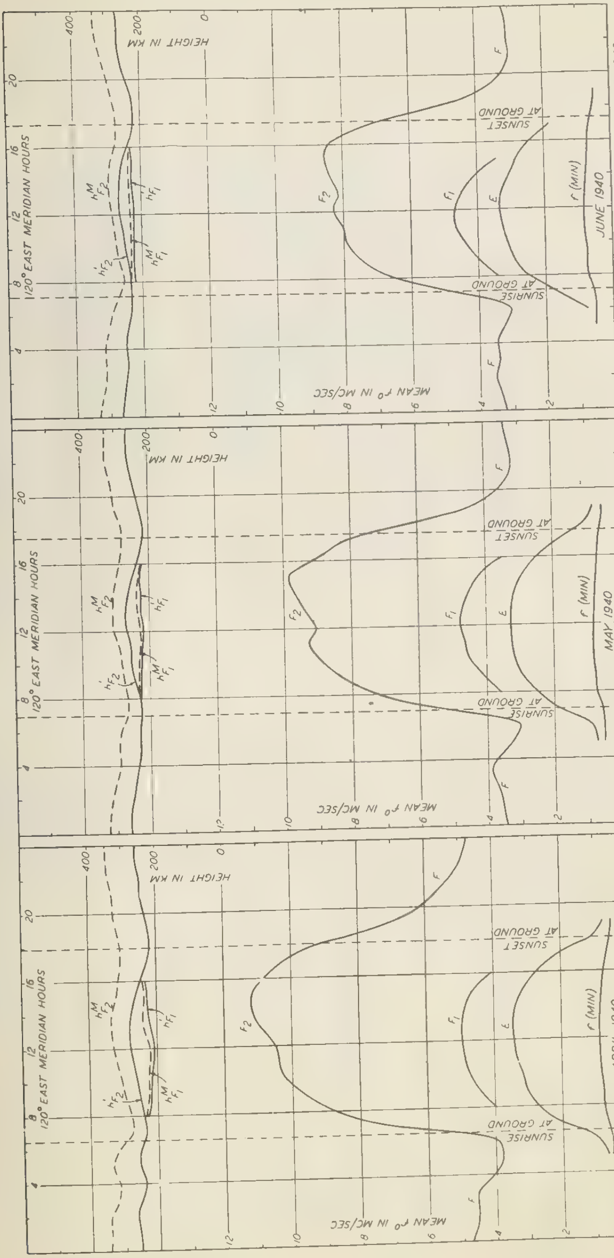


FIG. 2—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, APRIL, MAY, AND JUNE, 1940, WATHEROO, WESTERN AUSTRALIA

TABLE 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, January to June, 1940*—Concluded

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				June, 1940				
00			333	269			3.21	
01			326	261			3.39	
02			312	253			3.52	
03			312	246			3.41	
04			314	253			3.48	
05			305	248			3.26	0.51
06			292	239	0.78		3.02	0.52
07			275	232	1.61		4.47	0.57
08	(238)	(220)	253	226	2.50	3.40	6.52	0.75
09	231	226	266	238	2.90	3.99	7.40	0.75
10	232	224	275	250	3.11	4.38	7.88	0.80
11	232	221	280	255	3.25	4.67	7.99	0.84
12	233	223	287	264	3.37	4.68	8.30	0.83
13	235	223	296	269	3.30	4.50	8.11	0.83
14	238	230	296	264	3.07	4.14	8.37	0.79
15	238	228	293	257	2.86	3.46	8.53	0.76
16	236	232	277	238	2.47		8.43	0.71
17			271	223	1.85		7.47	0.68
18			272	220			5.45	0.59
19			284	229			3.90	0.53
20			297	242			3.28	
21			310	256			3.00	
22			324	264			3.07	
23			333	264			3.10	

when that frequency was higher than 0.516 mc/sec, which is the lower limit of the frequency-sweep used (0.516 to 16.0 mc/sec). Figures 1 and 2 give the above data in graphical form; the values of h^{min} lie along the continuous line while those of h^{max} are indicated by the broken line.

The 120° east meridian standard times of sunrise and sunset for the middle of each month are shown by the broken vertical lines.

WATHEROO MAGNETIC OBSERVATORY,
Watheroo, Western Australia, August 23, 1940,

THE IONOSPHERE AT HUANCAYO, PERU, JANUARY TO JUNE, 1940

By H. W. Wells and R. C. Coile

This report is a continuation of those already published in this Journal[1] and gives monthly mean hourly values of the heights and penetration-frequencies of the ionospheric regions as obtained from the automatic multifrequency ionospheric recording apparatus. A complete discussion of these data will be made in an annual summary at the end of 1940.

Commencing with January, 1940, some desirable changes were made in the scaling of the heights of the layers. Besides the minimum virtual height, the actual heights of maximum electron-density, uncorrected for presence of lower layers, are now scaled, using the method described by Booker and Seaton[2].

Table 1 gives the mean hourly values of the actual heights of maximum electron-density (h^{max}) and the minimum virtual heights (h^{min})

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, January to June, 1940*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				January, 1940				
00			371	287			6.75	
01			347	284			5.73	
02			337	279			5.19	
03			324	278			4.57	
04			312	276			3.90	
05			317	277	0.76		3.63	0.67
06			321	264	1.86		6.04	0.74
07			337	242	2.63		8.51	0.84
08	240	230	391	292	3.05	4.68	9.84	1.02
09	234	221	466	332	3.46	4.96	10.08	1.26
10	224	216	498	369	3.70	5.04	9.69	1.43
11	217	212	487	372	3.89	5.08	9.30	1.74
12	214	211	489	377	3.90	5.08	9.32	1.81
13	210	206	470	367	3.79	5.01	9.71	1.77
14	211	205	470	355	3.72	4.89	10.08	1.66
15	212	206	460	328	3.51	4.66	10.41	1.49
16	233	218	448	315	3.11	4.50	10.74	1.14
17			436	250	2.69		10.96	0.86
18			430	272	1.98		11.17	0.75
19			443	296	1.04		10.76	0.69
20			480	320			9.68	
21			464	334			8.91	
22			438	315			8.35	
23			404	306			7.64	

[1]Terr. Mag., **43**, 169-171, 257-260, and 467-470 (1938); **44**, 85-88, 195-198, 321-325, and 395-399 (1939).
[2]Phys. Rev., **57**, 87-94 (1940).

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, January to June, 1940*—Continued

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_{E}	$f^{\circ}_{F_1}$	$f^{\circ}_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				February, 1940				
00			336	247			8.47	
01			315	230			7.63	
02			306	240			6.43	
03			307	247			5.76	
04			304	251			5.26	
05			295	245	0.81		4.52	0.71
06			305	258	1.67		5.79	0.78
07			311	241	2.58		8.71	0.90
08	232	223	349	275	3.08	4.74	10.35	1.17
09	228	214	408	293	3.48	4.95	11.15	1.37
10	215	210	456	310	3.74	5.05	11.29	1.75
11	210	205	478	319	3.89	5.12	10.86	1.85
12	208	204	470	335	3.94	5.17	10.56	1.89
13	204	202	466	325	3.87	5.07	10.49	1.97
14	201	200	454	311	3.80	4.94	10.74	1.94
15	208	203	453	291	3.56	4.77	10.85	1.67
16	224	208	449	285	3.11	4.54	10.94	1.27
17			447	234	2.70		10.95	1.02
18			439	263	1.84		10.89	0.85
19			446	298	0.91		10.43	0.81
20			462	308			9.73	
21			445	304			9.30	
22			404	281			9.23	
23			370	265			9.07	
				March, 1940				
00			304	212			9.05	
01			300	211			8.31	
02			291	227			6.96	
03			289	230			5.98	
04			289	238			5.08	
05			289	242	0.81		4.49	0.72
06			304	260	1.66		5.72	0.78
07			299	236	2.64		8.79	1.02
08	243	227	338	269	3.14	4.92	10.97	1.30
09	234	219	395	280	3.54	5.04	11.87	1.82
10	225	211	442	290	3.81	5.28	11.78	2.00
11	210	209	464	317	4.02	5.25	11.10	2.16
12	205	204	446	301	4.00	5.22	10.81	2.12
13	206	202	447	304	3.98	5.21	10.96	2.15
14	205	201	459	290	3.80	5.06	11.04	1.97
15	212	205	453	274	3.55	4.80	11.21	1.85
16	225	207	460	264	3.09	4.45	11.22	1.32
17			461	240	2.63		11.15	1.00
18			451	265	1.61		10.88	0.84
19			493	337	0.91		10.03	0.81
20			477	325			9.36	
21			393	279			9.45	
22			359	235			9.36	
23			320	220			9.37	

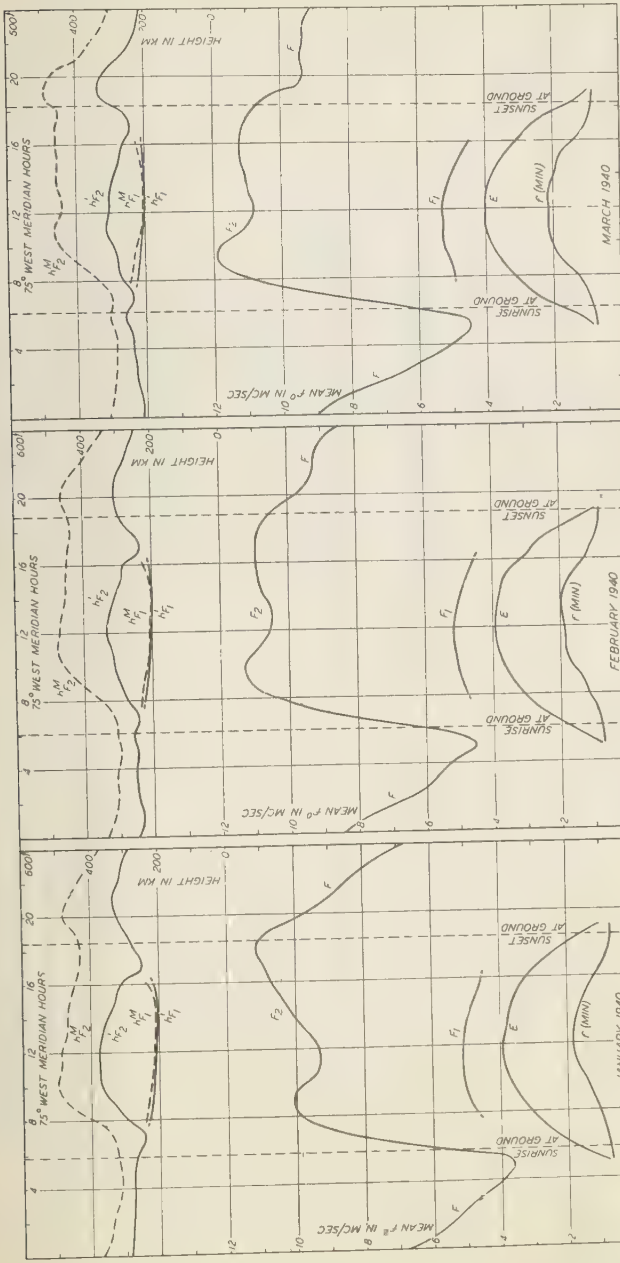


FIG 1A—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, JANUARY, FEBRUARY, AND MARCH, 1940. HUANCAYO, PERU

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, January to June, 1940*—Continued

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_{E}	$f^{\circ}_{F_1}$	$f^{\circ}_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
				April, 1940				
00			291	215			8.18	
01			292	220			7.51	
02			291	226			6.52	
03			293	239			5.62	
04			291	241			4.96	
05			283	237	0.77		4.35	0.66
06			311	259	1.57		5.69	0.69
07			302	237	2.47		8.69	0.90
08	238	228	342	260	3.01	4.75	10.42	1.20
09	234	219	392	279	3.53	5.09	11.14	1.70
10	220	210	420	287	3.72	5.25	10.86	1.95
11	212	204	433	295	3.83	5.30	10.42	2.03
12	208	203	435	297	3.85	5.30	10.41	1.99
13	205	199	435	296	3.78	5.22	10.67	1.87
14	206	200	438	283	3.59	4.99	10.95	1.72
15	210	202	438	266	3.35	4.59	10.97	1.45
16	236	215	445	266	2.98	4.38	11.13	1.18
17			449	253	2.41		11.12	0.96
18			465	285	1.22		10.70	0.84
19			477	317	0.79		9.41	0.72
20			419	284			9.19	
21			364	249			9.10	
22			315	219			8.80	
23			292	215			8.33	
				May, 1940				
00			283	217			6.66	
01			285	222			6.07	
02			289	227			5.66	
03			291	244			4.83	
04			295	248			4.31	
05			292	251	0.70		3.95	0.64
06			308	261	1.34		4.89	0.73
07			300	237	2.43		7.44	0.78
08	239	221	336	268	2.93	4.68	9.24	1.07
09	229	213	374	288	3.25	4.93	9.80	1.24
10	219	205	413	301	3.50	5.06	9.57	1.40
11	211	204	422	319	3.64	5.06	9.14	1.53
12	207	202	417	320	3.65	5.01	8.76	1.63
13	203	198	423	310	3.59	4.95	8.61	1.47
14	211	199	431	305	3.44	4.87	8.81	1.35
15	222	206	412	284	3.16	4.59	8.95	1.22
16	245	218	409	277	2.73	4.35	8.99	1.02
17			403	254	2.05		8.83	0.86
18			414	287	0.97		8.58	0.72
19			420	290	0.82		8.02	0.64
20			379	264			8.13	
21			326	231			8.24	
22			291	214			7.71	
23			287	216			6.73	

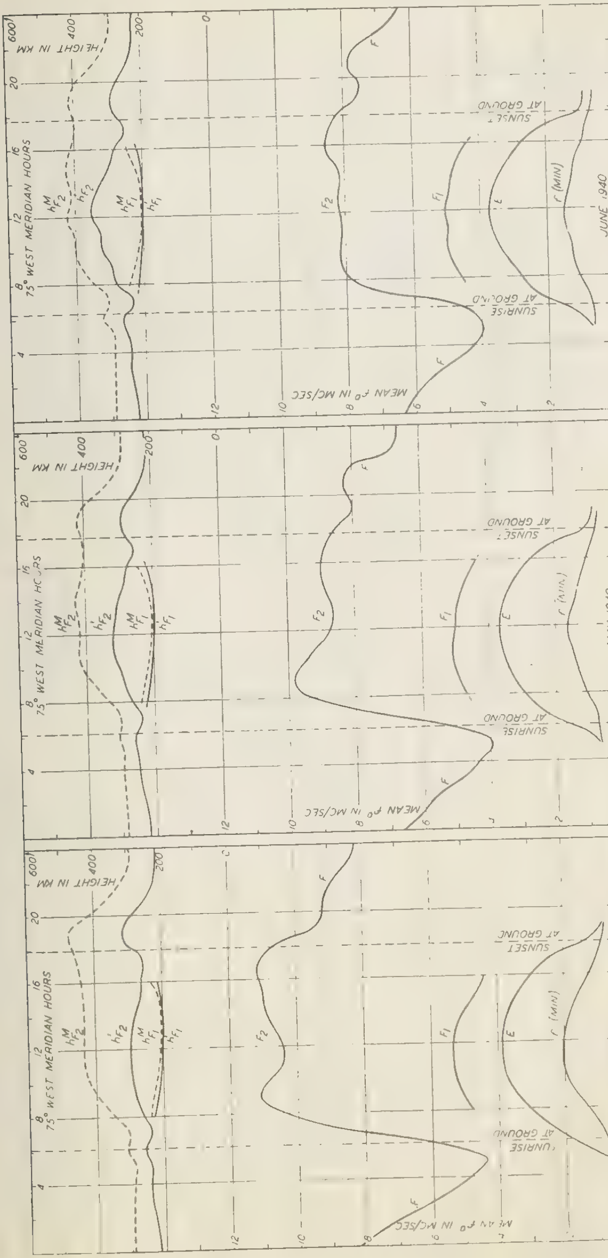


FIG. [illegible]—MEAN CRITICAL FREQUENCY (f^0), MINIMUM HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, APRIL, MAY, AND JUNE, 1940. HUANCAYO, PERU

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, January to June, 1940*—Concluded

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	km	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec
				June, 1940				
00			290	221			6.35	
01			290	227			6.06	
02			293	236			5.63	
03			293	243			4.90	
04			291	242			4.26	
05			291	252	0.68		3.94	0.61
06			325	267	1.24		4.30	0.62
07			309	233	2.33		6.46	0.77
08	242	217	348	282	2.78	4.57	7.85	1.01
09	227	211	382	292	3.19	4.82	8.17	1.21
10	217	206	401	321	3.49	5.00	8.17	1.26
11	208	203	407	328	3.66	4.97	8.11	1.46
12	204	201	425	353	3.72	5.05	8.18	1.46
13	207	202	412	348	3.63	4.93	8.27	1.37
14	208	201	420	325	3.44	4.85	8.15	1.25
15	227	204	427	299	3.12	4.68	8.36	1.16
16	245	215	412	283	2.76	4.38	8.58	0.95
17			400	251	2.06		8.45	0.81
18			404	277	0.97		8.13	0.65
19			413	292	0.86		7.54	0.59
20			395	274			7.63	
21			344	243			7.86	
22			307	228			7.49	
23			293	225			6.76	

TABLE 2—*Root-mean-square values of F_2-region penetration-frequencies ($f^\circ_{F_2}$), Huancayo Magnetic Observatory, January to June, 1940*

EST	Jan.	Feb.	Mar.	Apr.	May	June
h	mc/sec	mc/sec	mc/sec	mc/sec	mc/sec	mc/sec
00	6.87	8.55	9.11	8.28	6.78	6.40
01	5.83	7.72	8.38	7.63	6.15	6.12
02	5.30	6.55	7.03	6.69	5.78	5.74
03	4.69	5.97	6.06	5.81	4.91	5.05
04	4.06	5.56	5.23	5.19	4.40	4.38
05	3.77	4.87	4.69	4.63	4.10	4.22
06	6.07	5.88	5.78	5.81	4.95	4.43
07	8.56	8.74	8.88	8.72	7.48	6.48
08	9.87	10.37	10.99	10.45	9.26	7.88
09	10.14	11.20	11.90	11.17	9.84	8.19
10	9.78	11.34	11.82	10.93	9.63	8.26
11	9.42	10.94	11.14	10.49	9.19	8.13
12	9.40	10.65	10.86	10.47	8.79	8.21
13	9.78	10.55	11.00	10.70	8.63	8.30
14	10.15	10.79	11.07	10.98	8.84	8.18
15	10.46	10.88	11.25	10.99	8.98	8.38
16	10.80	11.00	11.27	11.16	9.02	8.60
17	11.02	11.03	11.18	11.15	8.85	8.47
18	11.21	10.96	10.94	10.74	8.61	8.16
19	10.80	10.50	10.06	9.48	8.07	7.59
20	9.77	9.80	9.44	9.26	8.18	7.66
21	9.02	9.36	9.53	9.20	8.29	7.92
22	8.47	9.30	9.44	8.90	7.76	7.53
23	7.74	9.14	9.44	8.42	6.80	6.80

for both the F_1- and the F_2-regions, as also the penetration-frequencies for the E-, F_1-, and F_2-regions and the minimum frequency recorded when that frequency was higher than 0.516 mc/sec—the lower limit of the frequency-sweep used (0.516 to 16.0 mc/sec). Figures 1-*A* and 1 give the above data in graphical form: The values of h^{min} lie along the continuous line while those of h^{max} are indicated by the broken line.

The 75° west meridian standard times (EST) of sunrise and sunset for the middle of each month are shown by the broken vertical lines.

Table 2 gives root-mean-square values of F_2-region penetration-frequencies for January to June, 1940. Since ionization is proportional to the square of frequency, these data are more representative of *average ionization* than the normally used means of penetration-frequencies. The difference between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 is an approximate measure of the scatter in individual observations during the month for that particular hour. Root-mean-square values for the E-region, F_1-region, and minimum frequency received have been discontinued because of the absence of appreciable differences between the root-mean-square and arithmetical-mean values.

HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, June, 1940

REVIEWS AND ABSTRACTS

P. J. NOLAN: *Estimation of the air-earth current.* Proc. R. Irish Acad., A, **46**, 65-75, with 2 figs. (1940).

Observations taken at Glencree, Ireland, on the potential-gradient and conductivity of the atmosphere and of the air-earth current with a Wilson test-plate between November, 1937, and July, 1939, form the basis of this paper. A comparison of the air-earth current at ground-level by the direct method (Wilson test-plate) and the indirect method (conductivity times potential-gradient, both measured at one meter), published in 1937 by J. J. Nolan and P. J. Nolan, indicated that the values obtained by the latter method exceeded those obtained by the former by about ten per cent. Hogg in 1939 found good agreement between the two methods of obtaining the air-earth current when the conductivity and potential-gradient were measured at heights between 12.5 and 100 cm. The paper under review reports upon further comparisons, the conductivity and potential-gradient having been measured at a height of one meter, giving results similar to those obtained previously.

Incidentally it is of interest to note that on several occasions a negative current was measured with the Wilson plate although the potential-gradient was positive. The magnitude of this current was generally small, between 1 and 3×10^{-7} esu, and generally occurred during mist, rain, or dew. Scrase had previously noted a negative current with a positive potential-gradient which occurred during a fog. This negative current is believed by the author to be due to the collection of negatively charged droplets by the plate.

The atmospheric conductivity, obtained by means of a special aspiration-method, exceeded that obtained by the Wilson plate by about 12 per cent. This difference, the author believes, is due for the most part to an upward current brought about by turbulence. From 188 observations a mean value of 2.1×10^{-4} esu was obtained for the conductivity. This was not considered an average value for Glencree, however, for the measurements were generally made while the conductivity was above normal. The mean air-earth current from 139 observations with the Wilson plate was 8.1×10^{-7} esu referred to an open site. Neither is this value considered by the author as a true annual mean for Glencree.

These results, together with those obtained previously, compel one to reject Watson's contention that the indirect method of obtaining the air-earth current gives values approximately twice as large as those obtained with the Wilson plate.

G. R. WAIT

J. A. FLEMING (Editor): *American Geophysical Union, Transactions of 1940.* Washington, D. C., National Research Council, 1151 pp. with illus. (July 1939). 25 cm.

The *Transactions* of the American Geophysical Union for 1940 are published in four parts: Part I contains the reports and papers, joint regional meeting Section of

Hydrology and Western Interstate Snow-Survey Conference, South Pacific Coast Area, Stanford University, California, January 12-13, 1940; Part II, reports and papers and minutes, twenty-first annual meetings of the American Geophysical Union and its sections (General Assembly, Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Oceanography, Volcanology, Hydrology, and Tectonophysics), Washington, D. C., April 24-27, 1940; Part III, symposium with American Association for the Advancement of Science (Sections *D* and *E*) and Geological Society of America, Richmond, Virginia, December, 1938, on "The surface and subsurface exploration of continental borders," reports and papers of joint regional meeting, Western Interstate Snow-Survey Conference and Section of Hydrology, North Pacific Coast and North Continental Divide Areas, Seattle, Washington, June, 1940; Part IV, symposia with American Association for the Advancement of Science (Sections *A* and *E*), American Mathematical Society, Ohio Academy of Science, Geological Society of America, American Meteorological Society, and Section of Hydrology, Columbus, Ohio, December, 1940, on "Application of mathematics in the Earth-sciences" and "Hydrologic problems in the Ohio and Michigan basins."

The scientific session of the General Assembly consisted of a symposium on "Tectonophysics of the crust" at which four papers were presented dealing with (1) seismology and the first hundred kilometers of the Earth, (2) thermal measurements and their bearing on crustal problems, (3) deformation of rocks in the laboratory, and (4) the mountain-building cycle.

Of particular interest to readers of this Journal are the papers, 12 in number, presented before the Section of Terrestrial Magnetism and Electricity and reproduced in Part II of the Transactions. An idea of the scope of these contributions may be gathered from the titles which are as follows: Some features of the large geomagnetic tides in the horizontal force at Huancayo, by J. Bartels and H. F. Johnston; Physical representations of the geomagnetic field, by A. G. McNish; Note on surface-field analysis, by E. H. Vestine; Magnetic studies of the Florida Peninsula, by F. W. Lee and J. H. Swartz; A comparison of magnetic, seismic, and gravitational profiles on three traverses across the Atlantic Coastal Plain, by G. P. Woollard; Height of magnetic anomalies, by H. H. Howe; Description of Missouri School of Mines Magnetic Observatory, by F. C. Farnham; Ionospheric measurements during the solar eclipse of April 7, 1940, by L. V. Berkner and S. L. Seaton; The distribution of electric elements in the atmosphere near the Earth's surface, by O. H. Gish; Total and uncharged nuclei at Washington, D. C., by K. L. Sherman; The nature of the solar hydrogen vortices, by R. S. Richardson; The evaluation of magnetic anomalies by means of scales, by I. Roman. There were also presented three reports (1) by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington on researches in terrestrial magnetism and electricity, (2) by the United States Coast and Geodetic Survey on magnetic work, and (3) by the National Bureau of Standards on ionosphere research.

At the General Assembly on April 26, 1940, the second award of the William Bowie Medal, endowed by friends of the late Dr. William Bowie and established by vote of the Executive Committee of the Union on March 1, 1939, for distinguished attainment and outstanding contribution to the advancement of cooperative research in fundamental geophysics, was made to Dr. Arthur L. Day, formerly director of the Geophysical Laboratory of the Carnegie Institution of Washington. Six resolutions were adopted, none of which originated in the Section of Terrestrial Magnetism and Electricity. They pertained to repositories for geophysical records, compilation and investigation of sounding data, seismological stations in the North Atlantic, seaward extension of submarine valleys, analysis and publication of data on rainfall and runoff, and United States Naval Observatory time-signals.

In the Symposium on Applications of mathematics in the Earth-sciences, published in Part IV, Prof. Lachlan Gilchrist gave a paper on "The use of mathematics in the delineation of magnetic and electric anomalies," applying standard mathematical processes to the measurement of magnetic and electric anomalies due to the presence of deposits of mineral which modify the magnetic intensity and electrical conductivity, respectively.

As in past years, the *Transactions* of 1940 have been produced by the planographic method and the general excellency in all respects characteristic of previous issues has been maintained. The considerable increase in their contents, partly owing to the papers originating in the newly established Section of Tectonophysics and partly to the extensive regional meetings in connection with the Section of Hydrology, bears witness to the ever-expanding interests of geophysics.

H. D. Harradon

GEOMAGNETIC TIDES IN HORIZONTAL INTENSITY AT HUANCAYO

By J. Bartels and H. F. Johnston

Part II[1]

§ 20. *A new viewpoint for computing* L

After the completion of Part I and of the summary [reference 4 in Part I], a new viewpoint was found which seemed likely to lead to better methods than those used hitherto in the computation of the lunar diurnal variation L, for the main term $L(M_2)$ arising from the partial tide M_2 and also the subsidiary terms depending on lunar distance. This led to a "principle of efficient sampling in geophysical statistics" (21), a general expression for ideas underlying previous work. This principle when applied to present methods of computing L, reveals the main reason for the rather unsatisfactory results of former computations on L. These results showed irregularities indicating the presence of large residuals due to non-lunar influences, both "regular" (such as that due to the average value of the solar daily variations S)—believed to be eliminated—and "irregular" (such as that due to disturbance or the variability of S) believed to be sufficiently "overwhelmed" by combining a great number of observations. L is mainly given by the semimonthly waves in the hourly means; these must be determined piecemeal from successions of undisturbed days. This computation of a wave from fragments is illustrated in Table 9 of Part I. A different order of magnitude of S in each fragment obviously introduces error in the result obtained for L; this becomes clear in the change of the average in Table 9 if a few days or groups of days are omitted. Table 9 gives $L(M_2)$; for $L(N_2)$, the main distance-term, this error is worse, because it is derived from still smaller fragments, namely, groups of days centered at perigee, apogee, etc.

A remedy could be found by a more elaborate treatment, determining S and L from each fragment separately by least-square methods. In practice, however, it is more convenient to abstract L from the *changes in the diurnal variations from one day to the next*. The phase of a semimonthly wave changes by 720°/29.531 days = 24°.38 per day; the semimonthly wave in the *changes* of an hourly mean from day to day has therefore an amplitude which reaches the fraction (2 sin 12°.19) = 0.4223 of the amplitude of the semimonthly wave in the hourly mean itself, as shown in § 22.

§ 21. *The principle of efficient sampling in geophysical statistics*

The viewpoints discussed in the latter part of § 8 (Part I) may be generalized to yield a guiding statistical principle for the treatment of time-series, applicable in those problems of geophysics in which a small quantity (q, say) shall be derived from a large, but necessarily finite, aggregate of observations of a phenomenon p in which fluctuations of

[1]Part I appeared in Terr. Mag., 45, 269-308 (1940).

larger magnitude than q, both regular and irregular, are superposed on q. The phenomenon p may be one-dimensional (atmospheric pressure at one station) or of more dimensions (geomagnetic-force vector). The quantity q may be one-dimensional (for instance, the change of p from new Moon to first quarter), two-dimensional (for instance, a sine-wave), or of higher dimensions (for instance, a daily variation expressed in hourly means). We seek the most accurate description of q permissible from the total given aggregate of observations, that is, a value for q deviating least from that to be obtained from an infinite supply of similar data.

In practice the accuracy of q is expressed by the standard deviation $\sigma(p)$ of p or some similar parameter measuring the scatter, for instance, the probable-error circle in the harmonic dial. Under random conditions, the law of propagation of errors asserts that the standard deviation σ_n for the average of n individual determinations with the standard deviation σ_1 is

$$\sigma_n = \sigma_1/\sqrt{n} \tag{21.1}$$

A deviation from random conditions, which is a common feature for geophysical time-series, may result in a different relationship between σ_n and σ_1, to be expressed by a parameter ϵ_n so that

$$\sigma_n = \sigma_1/(n/\epsilon_n)^{1/2} \tag{21.2}$$

ϵ_n has been called the equivalent number of repetitions, and (n/ϵ_n) is the number of effectively independent observations [1]. The conception of ϵ_n is quite general; the time-intervals for the n individual determinations need not be consecutive.

$(\epsilon_n = 1)$ signifies random conditions. Asymptotic quasi-persistence is signified by ϵ_n = practically constant for $n > n_q$, say. Then, for $n = kn_q$

$$\sigma_n = \sigma_{(n/k)}/\sqrt{k} \tag{21.3}$$

simulating random conditions. In practice it is convenient to estimate n_q and σ_{nq} since then, with further increase of n, the ordinary law of propagation of errors prevails. The principle of efficient sampling requires us to choose such an expression for q and such a form of calculating it, that the standard deviation of the final result, relative to the quantity itself, is smallest.

These considerations imply an initial increase in computational labor but make for gains in efficiency. In material (such as sunspot-numbers R) with high quasi-persistence, a good average for a calendar year, for instance, is well approximated by the average for 20 selected days distributed either at random or evenly throughout the year.

§ 22. *Application to the computation of* L

The position of the mean Moon (mean longitude s) in its orbit is given for each day by its mean distance $\nu = (s - h)$ from the mean Sun (mean longitude h) and its mean distance $(s - p)$ from perigee, both at Greenwich mean noon; in practice, by a pair of integers ν and $(s - p)$,

with $\nu=0^h, 1^h, 2^h, \ldots 23^h$, and $(s-p)=0, 1/8, 2/8, \ldots 7/8$ of the anomalistic months. The centers for the eighths (of 45° each) $(s-p)=$ 0, 2, 4, and 6 coincide with those of the groups (of 90° each) PER, REC, APO, NEA described in § 2, (5). In other words, if ν and $(s-p)$ are expressed in degrees, the integer numbers designating the groups are the round values of $(\nu/15°)$ and $[(s-p)/45°]$.

All undisturbed days of a calendar month and a sunspot-group are thereby divided into $(24\times 8)=192$ groups according to all possible combinations $[\nu, (s-p)]$. Now, for horizontal intensity, H, at Huancayo, the group January Min_1 (years 1923, 1924, 1932, 1933, and 1934) con-

TABLE 13—*Undisturbed days in the months of January, 1923, 1924, 1932, 1933, 1934; frequency-distribution according to ν and $(s-p)$*

$(s-p)$	$\nu=$ 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum
0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	4	.	2	1	1	.	9
1	2	2	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	1	2	4	17
2	2	2	1	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	11
3	.	1	2	1	1	3	3	2	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15
4	.	.	.	.	1	2	2	2	1	1	3	1	.	.	.	.	.	.	.	.	.	.	.	.	13
5	.	.	.	.	.	.	.	3	2	3	3	2	3	2	.	1	1	.	.	.	.	.	.	.	20
6	.	.	.	.	.	.	.	.	.	.	1	5	2	1	2	1	.	2	1	.	.	.	.	.	15
7	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	1	2	2	2	1	1	2	.	.	14
Sum	4	5	5	2	3	6	6	7	4	5	7	8	5	5	3	3	3	5	7	3	4	4	4	6	114

tains 114 undisturbed days, distributed quite unevenly as shown in Table 13. This is due to the fact that the difference

$$\nu-(s-p)=(s-h)-(s-p)=p-h$$

changes by only 27°.1 within 31 days, since the periods of p and h are, respectively, 8.85 years and one year; within a calendar month, ν and $(s-p)$ differ therefore approximately by a constant. The necessary subdivision according to the sunspot-number R, by an unfortunate coincidence, causes an uneven distribution for the totals obtained for five months of January, because the 11-year cycle in R differs too little from the nine-year period p. Another unfavorable influence, likewise of solar origin, is the 27-day recurrence-tendency of magnetic disturbance, which coincides nearly with the period of ν; the exclusion of disturbed days, which occur mostly in succession, is therefore likely to affect certain values of ν more than others, making the distribution more uneven.

However, the situation appears in a more favorable light if we remember that the semidiurnal tides all have nearly the frequency $2\tau=2(t-\nu)$, apart from slowly changing phases such as $(s-p)$, or, if t is fixed (fixed-hour method), the frequency is 2ν. Considering changes from day to day, therefore, the change up to a day with $\nu=2$, say, from the preceding day, is systematically the same as that up to a day with $\nu=14$; and if the signs of the change up to days with $\nu=8$ or 20, are reversed, they can be combined with those up to $\nu=2$. This reduces the number of ν-groups to six, with $\nu=0$ to 5, and Table 13 is condensed

TABLE 14—*Frequency-distribution undisturbed days according to ν and $(s-p)$, for data of Table 13, combining values of ν for 0, 6, 12, and 18, for 1, 7, 13, and 19, and so forth*

$(s-p)$	$\nu=$						Sum
	0	1	2	3	4	5	
0	4	0	2	1	1	1	9
1	2	4	3	2	2	4	17
2	3	2	1	0	2	3	11
3	3	3	3	2	1	3	15
4	2	2	1	1	4	3	13
5	3	5	2	4	4	2	20
6	3	1	2	1	1	7	15
7	2	3	2	3	2	2	14
Sum	22	20	16	14	17	25	114

into Table 14. The change of $\sin(2\nu+\epsilon)$ for a change from $(\nu-\triangle\nu)$ to ν is

$$\sin(2\nu+\epsilon)-\sin(2\nu-2\triangle\nu+\epsilon)=2\cos(2\nu+\epsilon-\triangle\nu)\sin\triangle\nu \qquad (22.1)$$

Since days with integer values of ν are combined, their average is that for an interval of width 15° in ν or 30° in 2ν. Therefore, for a wave $[c\sin(2\nu+\epsilon)]$, the average difference leading to a day with a round value ν from the preceding solar day is, with $\triangle\nu=12°.19$

$$2c\sin\triangle\nu\times[\sin 15°/(\mathrm{arc}\ 15°)]\cos(2\nu+\epsilon-\triangle\nu) \qquad (22.2)$$

Compare this with the unsmoothed average difference of the wave $[c\sin(2\nu+\epsilon)]$ leading to a round value of ν from the preceding round value of ν, that is, $(\nu-1$ hour$)$ or $(\nu-15°)$, which is [replacing $\triangle\nu$ in (22.1) by $\triangle\nu=15°$]

$$2c\sin 15°\cos(2\nu+\epsilon-15°) \qquad (22.3)$$

Now, from differences such as (22.3), c and ϵ could be determined by consecutive adding of the differences from day to day to obtain the wave $[c\sin(2\nu+\epsilon)]$ in the hourly means, which is then determined by ordinary harmonic analysis for 12 equidistant ordinates. If we apply exactly the same computation to the differences (22.2) we obtain likewise an amplitude and a phase, but the amplitude must be multiplied by

$$\mathrm{arc}\ 15°/\sin\triangle\nu=\mathrm{arc}\ 15°/\sin 12°.19=1.240 \qquad (22.4)$$

in order to obtain c, and the phase must be increased by

$$\triangle\nu-15°=12°.19-15° \qquad (22.5)$$

that is, *decreased* by 2°.81 in order to obtain ϵ. The actual procedure of computation is given in § 23.

§ 23. *Calculation of the group-sums for two-fold changes*

Monthly tables of interhourly differences in horizontal intensity are tabulated for each undisturbed day from the hourly-value sheets. Since the method requires that the change from the preceding day be computed, interhourly differences for an undisturbed day are tabulated only when

there is a succession of at least two such days. For each day the first difference is the algebraic change from the mean value of H for the hour 00^h-01^h to that for the hour 01^h-02^h GMT, the second that from 01^h-02^h to 02^h-03^h and so on for 24 consecutive differences. The sum of the 24 differences is the non-cyclic change, which is a ready check.

The age of the mean Moon at Greenwich mean noon, ν, and the angular difference of the mean Moon from its perigee $(s-p)$ are entered for each day in the interhourly-difference tables. Then for each month of the year and combining all those of the same month for each of the sunspot-groups given in Table 1-*A*, a set of six sheets is prepared, one each for $\nu=0$, 1, 2, 3, 4, and 5. The dates of the days on which ν was 0, 1, . . . 5 are next entered on the appropriate sheets using tables similar to Table 14. The dates on each ν-sheet are grouped in accordance with the following arrangement of ν and $(s-p)$: (0, 0) (0, 4); (0,1) (0, 5); (0, 2) (0,6); and (0, 3) (0, 7). Then, utilizing the interhourly-difference tables, the *changes from the preceding day*, "plus" for $\nu=0$, 1, . . . 5, and "minus" for $\nu=6$, 7, . . . 11 are entered. These are *two-fold changes*, from hour to hour, and from day to day. Group-sums $(\nu, s-p)$ and ν-totals are added for each sheet. Finally the ν-totals are adjusted for the non-cyclic change and the average changes to 0.1 gamma formed by dividing by the total number of days. The average changes are slightly adjusted so that the sums of the positive and negative terms are exactly zero.

§ 24. *Final computation of $L(M_2)$*

The average changes from six sheets $\nu=0$, 1, . . . 5 are tabulated on a summary sheet. The wave is then completed from vertical successive summing as follows: If the six day-to-day changes in one vertical column are X_0, X_1, X_2 X_3, X_4, X_5, then the next six changes completing one cycle in 2ν are $X_6=-X_0$, $X_7=-X_1$, . . . $X_{11}=-X_5$. Successive summing gives the 12 ordinates of the semimonthly wave in δH, X_0, (X_0+X_1), . . . $(X_0+X_1+\ldots+X_{11})$, or if we put $X_6=-X_0$, etc., and write the waves in two halves, $\nu=0$ to 5 and 6 to 11,

$\nu=0$	$\nu=1$	$\nu=2$	$\nu=3$	$\nu=4$	$\nu=5$
X_0	X_0+X_1	$X_0+X_1+X_2$	$X_0+\ldots+X_3$	$X_0+\ldots+X_4$	$X_0+\ldots+X_5$
$+\ldots+X_5$	$X_2+\ldots+X_5$	$X_3+X_4+X_5$	X_4+X_5	X_5	0

This should be harmonically analyzed. We begin by subtracting the two halves, since $\sin(\alpha+180°)=-\sin\alpha$, and get $[X_0-(X_1+\ldots+X_5)]$, $[(X_0+X_1)-(X_2+\ldots+X_5)]$, ... $[(X_0+\ldots+X_5)=0]$. In the practical computation the process is as follows: Compute $(X_1+\ldots+X_5)$, subtract it from X_0 which gives the first value treated as for $\nu=0$; the second value is obtained by adding $2X_1$ to the first value; the third by adding $2X_2$ to the second; etc.; the values in the last line are $[X_0+(X_1+\ldots+X_5)]$ and hence a ready check. The next step is ordinary harmonic analysis for 12 ordinates, already folded to six ordinates; but instead of dividing by 6, we multiply [according to (22.4)] by $1.240/6=0.207$. Then the hourly changes are reverted into deviations from night-level 22^h-02^h by successive additions, the average for the four hours 22^h-02^h is made zero.

The result is two lines giving $L(M_2)$ but not exactly at $2\nu=0^h=0°$ and $2\nu=06^h=90°$, but at $2\nu=2°.8$ and $2\nu=92°.8$ or at $\nu=1°.4=0^h.1$ and at $\nu=46°.4=3^h.1$. Therefore, the phase of the wave $[c\sin(2\nu+\epsilon)]$ is obtained

from the phase determined by the two rows treated as ($a \cos 2\nu + b \sin 2\nu$) by subtracting 2°.8 from that phase obtained as arc tangent (first row/second row).

The total number of days analyzed was 1946. Table 15-*A* shows the

Table 15-*A*—*Number of days in horizontal intensity at Huancayo analyzed for $L(M_2)$; the bracketed six numbers give the individual totals for $\nu=0, 1, 2, 3, 4, 5$,* respectively

Sunspot-group	Month					Totals
	November	December	January	February	March	
Min_1	112 (23, 18, 17, 17, 20, 17)	123 (21, 18, 18, 19, 22, 25)	114 (22, 20, 16, 14, 17, 25)	101 (20, 16, 15, 16, 17, 17)	108 (17, 20, 15, 17, 18, 21)	558
Min_2	72 (14, 11, 12, 13, 11, 11)	76 (12, 12, 12, 15, 13, 12)	72 (11, 12, 12, 12, 13, 12)	64 (11, 11, 12, 9, 9, 12)	90 (14, 14, 12, 16, 16, 18)	374
Max_3	105 (20, 14, 19, 21, 16, 15)	114 (23, 22, 15, 19, 18, 17)	93 (15, 17, 13, 18, 14, 16)	79 (16, 15, 13, 12, 11, 12)	101 (14, 17, 17, 17, 19, 17)	492
Max_4	103 (16, 17, 14, 18, 19, 19)	116 (17, 19, 19, 19, 23, 19)	108 (18, 21, 20, 17, 14, 18)	94 (13, 15, 15, 16, 19, 16)	101 (14, 17, 17, 17, 19, 17)	522
Totals	392	429	387	338	400	1946

number of days utilized in the months November, December, January, February, March, for each of the sunspot-groups Min_1, Min_2, Max_3, and Max_4. Each series of six numbers in parentheses gives the individual totals of days for $\nu=0, 1, 2, 3, 4, 5$, respectively, in each group. Table 15-*B* summarizes the analyses for $L(M_2)$ by sunspot-groups for each of five months, by months, by sunspot-groups, and by grand averages. The results of the analysis of each unit are tabulated in two rows expressed in units of 0.1 gamma for $2\nu=2°.8$ and $2\nu=92°.8$, respectively.

§ 25. *A preliminary calculation of $L(M_2)$ for determining suppression of* L *at night*

The months December, January, and February, in which L is greatest, were selected for a preliminary study of L hour by hour; in this calculation, made at an earlier stage, the change from day to day was not yet used. The main object of this calculation was to find how much L is suppressed at night; therefore, the average variation in the night had to be determined to fractions of a gamma. In these months a total of 1268 days with $C<1.2$ had been available for computing the range A 608 ($=84$ per cent of all days) in sunspot-minimum and 660 ($=81$ per cent of all days) in sunspot-maximum (see Table 1). Only a few of these days cannot be used here because the records failed on hours other than those used for computing A; but it was decided to reject, in addition, days with marked irregularities in the night hours—more exactly those on which, between 20^h and 04^h, any numerical change δH from one hourly mean to the next, regardless of sign, exceeded 7γ.

That it is justified to regard such a change δH as a sign of disturbance appears from the following values of average numerical changes δH for

those days with quiet nights in January which have been retained for this calculation; δH at 20^h means the change between the hourly means 19^h-20^h and 20^h-21^h, etc.

Average numerical change δH at	20^h	00^h	04^h
January, sunspot-group Min_1	2.0γ	1.6γ	1.9γ
January, sunspot-group Max_4	3.5γ	2.0γ	2.7γ

The systematic lunar effect on δH will be found considerably less than one γ for the nine hours 20^h to 04^h; it is therefore rather certain that the rejection of days in which at least one of the nine nightly changes δH is 8γ or more causes no appreciable spurious systematic effect [16] on the computed L-variation, but tends only to reduce the random fluctuations due to disturbance.

This selection reduces the number of available days in the three months in the sunspot-minimum group from 608 to 392 (=64 per cent), and in the sunspot-maximum group from 660 to 383 (=58 per cent).

Each Greenwich day, from 19^h to 19^h standard Huancayo time, was assigned to one of {3 (calendar months) times 4 (sunspot-groups) times 12 [values of ν or $(\nu-12)$ to the nearest hour, 00 to 11]} = 144 groups. From the tabulations of hourly values of H, a row of 24 changes δH to the nearest γ was written out for each day, beginning with δH for 20^h, that is, the excess of the hourly mean 20^h-21^h over the hourly mean 19^h-20^h. The sum of the 24 hourly changes is the non-cyclic change per day. All rows in a group were added. Combining further the 12 group-sums with ν or $(\nu-12)=00^h$ to 11^h, the row of the average δH for S is obtained. Each daily row is regarded as $[\mathrm{S}+\mathrm{L}(\nu)]$; furthermore, $\mathrm{L}(\nu+6)$ is assumed to be $[-\mathrm{L}(\nu)]$. Take, for instance, the groups {December, Min_1, $\nu=0$}, consisting of $n=9$ days, and {December, Min_1, $\nu=6$}, consisting of $n=5$ days; L (December, Min_1 $\nu=0$), expressed in δH in the unit 0.1γ, is then computed as

$$\text{Group-sum }\{\text{December, Min}_1,\ \nu=0\}-\text{group-sum }\{\text{December, Min}_1\ \nu=6\}-\{[4\times \mathrm{S}\ (\text{December, Min}_1)]/14\} \qquad (25.1)$$

These average rows were then further combined for the three months and (with weights proportional to 5, 3, 4, and 5, according to the number of months in each group) for the sunspot-groups to form an average L-variation for $\nu=0$, 1, 2, 3, 4, and 5 hours. Then the non-cyclic correction was applied, and the consecutive values δH were added to express L by deviations $\triangle H$ from a night level. Average S-variations were likewise formed. The consecutive addition of the hourly changes δH leaves an additional constant free, namely, the night level from which the deviations $\triangle H$ are reckoned. This level was chosen as that from 22^h to 02^h, that is, the sum of the values $\triangle H$ for these four hourly intervals is zero. For L it was simply assumed that $\triangle H=0$ for 00^h-01^h; this is to be tested later.

In doing so, we achieve elimination, with regard to L, of spurious semimonthly waves which are residuals of non-cyclic changes, or changes in the intensity of the equatorial ring-current; but we also eliminate, unintentionally, the real semimonthly wave which might exist at night—more exactly, during the four night hours centered at midnight. However, it can be shown independently that this real wave is so small that it can be neglected. Thus, if an appreciable lunar effect at night existed,

TABLE 15-B—*Summary of results L(M_2), Huancayo, in pairs of horizontal rows, in each of five months, and summaries by*

Month, group	No. days	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11
		Standard 75° west meridian hour										
		Sunspot-group "Min_1"										
Nov.	112	+ 8	−19	−14	−14	−19	−11	+ 36	+ 87	+133	+134	+100
		− 3	+ 3	+18	− 1	− 7	−25	− 37	− 33	+ 13	+ 48	+ 62
Dec.	123	+ 4	+10	+10	+ 9	+ 4	+ 7	+ 31	+ 45	+ 46	+ 15	− 44
		+ 3	−10	− 8	+10	+ 7	− 4	+ 4	+ 34	+103	+161	+168
Jan.	114	+ 7	+ 2	− 7	− 9	− 8	+11	+ 72	+102	+ 66	− 6	−147
		− 5	+ 5	0	− 3	− 2	− 6	− 13	+ 9	+ 96	+199	+253
Feb.	101	+ 6	+ 4	+ 2	+18	+16	+18	+ 62	+160	+208	+196	+145
		0	+ 6	+11	+ 6	− 3	−16	− 26	0	+ 81	+207	+267
Mar.	108	− 5	− 8	−10	− 2	+ 5	+ 8	+ 42	+151	+198	−189	+179
		− 2	− 3	+ 3	+15	+13	+10	− 20	− 59	− 40	− 17	+ 35
		Sunspot-group "Min_2"										
Nov.	72	+11	− 7	+ 7	+19	+16	+44	+ 88	+114	+110	+ 77	+ 18
		−10	− 3	+ 1	− 2	−12	−12	− 15	− 2	+ 7	+ 20	+ 44
Dec.	76	−10	−13	− 2	+18	− 3	+ 7	+ 67	+121	+132	+ 82	− 27
		+ 2	+ 5	+ 3	+ 7	+11	+ 4	0	+ 25	+ 94	+170	+211
Jan.	72	− 4	− 6	−10	− 8	−10	+12	+ 52	+ 70	+ 79	+ 78	+ 38
		− 7	+11	+ 7	− 7	− 1	0	+ 21	+ 72	+103	+171	+224
Feb.	64	+ 3	+10	− 2	−27	−19	−21	+ 26	+ 92	+138	+146	+106
		+ 5	+16	− 2	− 3	−12	−11	− 30	− 2	+ 81	+186	+262
Mar.	90	+ 8	+ 2	+ 3	− 7	− 3	− 8	+ 20	+ 75	+116	+147	+169
		+ 9	+ 8	+15	+22	+21	+20	− 10	− 54	− 16	+ 66	+142
		Sunspot-group "Max_3"										
Nov.	105	+ 5	− 4	+ 4	+23	+20	+33	+ 80	+151	+165	+153	+163
		+ 5	+26	+32	+38	+33	+ 4	− 28	− 56	− 3	+ 60	+152
Dec.	114	− 2	−16	−17	−13	+ 9	+60	+120	+195	+189	+ 90	− 29
		−13	+ 2	+21	+ 8	−11	−28	− 34	− 43	+ 44	+155	+274
Jan.	93	+10	− 2	− 2	− 4	+12	+37	+ 80	+146	+100	+ 19	− 80
		+ 9	− 1	−26	−15	−24	−34	+ 6	+128	+191	+339	+272
Feb.	79	− 2	+ 8	−17	−27	−24	− 7	+ 29	+118	+143	+122	+ 31
		− 5	− 3	+ 2	− 6	− 4	−14	− 48	+ 2	+145	+173	+219
Mar.	101	+23	+ 4	−23	− 1	+12	+ 8	+ 34	+144	+202	+215	+165
		+ 7	+21	+18	+ 4	− 1	−25	− 72	−107	− 79	+ 93	+266
		Sunspot-group "Max_4"										
Nov.	103	− 4	+ 5	− 4	− 1	−17	− 5	+ 58	+144	+218	+214	+126
		− 7	−11	−21	−27	−24	−27	− 20	+ 7	+ 61	+165	+214
Dec.	116	0	− 2	−13	−16	+ 6	+35	+ 89	+162	+147	+ 90	+ 10
		+ 3	+ 3	−11	−10	−19	−37	− 52	− 3	+ 82	+100	+124
Jan.	108	+ 4	− 5	− 9	−11	− 2	+26	+ 73	+ 93	+ 13	− 74	−187
		+ 7	−15	−17	−11	− 8	− 3	+ 30	+126	+222	+356	+401
Feb.	94	−12	− 5	+ 5	− 2	+13	+34	+ 77	+158	+213	+171	+154
		+ 9	+ 9	+ 2	− 2	+29	+22	− 37	− 21	+ 82	+234	+326
Mar.	101	− 3	+12	+ 7	+11	− 2	+ 9	+ 42	+123	+209	+223	+219
		− 2	+ 3	+20	+38	+25	+14	− 9	+ 8	+ 89	+202	+340
		Summary by months										
Nov.	392	+ 4	− 7	− 3	− 5	− 2	+12	+ 63	+124	+160	+150	+109
		− 3	+ 5	+ 9	+ 3	− 2	−16	− 26	− 23	+ 20	+ 77	+123
Dec.	429	− 1	− 4	− 5	− 2	+ 5	+29	+ 76	+129	+126	+ 67	− 23
		− 1	− 1	+ 1	+ 4	− 4	−17	− 22	+ 2	+ 80	+145	+192
Jan.	387	+ 5	− 3	− 7	− 8	− 2	+22	+ 70	+104	+ 61	− 6	−111
		+ 1	− 1	−10	− 9	− 9	−11	+ 10	+ 83	+157	+273	+296
Feb.	338	− 1	+ 4	− 2	− 6	0	+10	+ 52	+137	+182	+163	+115
		+ 2	+ 7	+ 4	− 1	+ 4	− 4	− 35	− 6	+ 96	+203	+271
Mar.	400	+ 5	+ 3	− 6	+ 1	+ 3	+ 5	+ 35	+125	+189	+196	+184
		+ 3	+ 7	+14	+20	+15	+ 5	− 28	− 51	− 9	+ 88	+199
		Summary by sunspot-groups and grand average										
Min_1	558	+ 4	− 2	− 4	0	0	+ 7	+ 49	+109	+130	+106	+ 47
		− 1	0	+ 5	+ 5	+ 2	− 8	− 18	− 10	+ 51	+120	+157
Min_2	374	+ 2	− 3	− 1	− 1	− 4	+ 7	+ 51	+ 94	+115	+106	+ 61
		0	+ 7	+ 5	+ 3	+ 1	0	− 7	+ 8	+ 54	+123	+177
Max_3	492	+ 7	− 2	−11	− 4	+ 6	+26	+ 69	+151	+160	+120	+ 50
		+ 1	+ 9	+ 9	+ 6	− 1	−19	− 35	− 15	+ 60	+164	+237
Max_4	522	− 3	+ 1	− 3	− 4	0	+20	+ 68	+136	+160	+125	+ 64
		+ 2	− 2	− 5	− 2	+ 1	− 6	− 18	+ 23	+107	+211	+281
Grand aver.	1946	+ 2	− 1	− 5	− 2	+ 1	+15	+ 60	+124	+143	+115	+ 55
		+ 1	+ 3	+ 3	+ 3	+ 1	− 9	− 20	+ 1	+ 69	+157	+215

units of 0.1 gamma, for $2\nu = 2°.8$ and $2\nu = 92°.8$, respectively, by sunspot-groups for months, sunspot-groups, and grand average

Standard 75° west meridian hour												
11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
Sunspot-group "Min₁"												
+ 8	− 60	− 78	− 72	− 41	+ 6	+ 37	+21	+ 6	+28	+17	+ 5	+ 5
+117	+126	+ 85	+ 24	− 46	− 63	− 55	−19	−13	−13	− 5	+ 8	− 9
− 74	− 78	−130	−130	−107	− 55	+ 3	+15	+ 3	+ 8	+10	− 8	− 5
+187	+130	+ 48	− 26	− 51	− 60	− 35	−16	+ 1	+ 7	−10	+ 2	+ 6
−295	−303	−284	−161	− 80	− 3	+ 24	+ 5	−15	−19	− 9	− 8	0
+227	+118	− 33	−163	−215	−163	− 78	− 9	+ 7	+ 1	− 4	− 1	+ 2
+ 80	− 68	−170	−237	−209	−126	− 18	+19	+ 5	− 8	− 7	− 6	− 5
+266	+218	+120	− 25	−125	−149	−112	−54	−21	− 8	− 1	− 7	0
+ 93	− 15	− 89	−117	−100	− 47	+ 19	+22	0	− 9	+ 3	+ 2	+11
+ 75	+ 95	+ 44	− 8	− 27	− 36	− 21	+12	+ 7	+16	+15	0	+ 5
Sunspot-group "Min₂"												
− 24	− 87	−144	− 94	− 18	+ 45	+ 59	+37	− 3	+10	+33	+ 4	−10
+ 83	+ 43	− 2	− 55	− 80	− 50	− 36	−24	−29	−23	−18	0	+13
− 59	−151	−172	−167	−111	− 24	+ 14	+25	+11	+ 1	− 4	+14	+ 9
+231	+226	+147	+ 35	− 77	−111	− 58	0	+ 7	+ 7	+ 3	− 4	− 3
− 5	− 93	−140	−182	−149	− 58	− 8	+21	+ 7	+ 6	+18	+10	− 1
+217	+169	+ 58	− 63	−117	−121	− 18	−35	−25	−38	−12	− 2	− 2
− 7	−163	−283	−222	−149	− 54	+ 11	+26	− 6	−26	−20	− 6	− 9
+361	+331	+218	+ 63	− 85	−149	−103	−46	− 4	−24	−29	−12	−11
+120	+ 83	+ 17	− 25	− 37	− 33	− 32	− 2	−11	+ 9	+ 3	−10	− 1
+185	+259	+206	+137	+ 12	− 90	−107	−60	−54	−45	+28	−16	+ 1
Sunspot-group "Max₃"												
+118	+ 13	− 35	− 90	− 78	− 43	+ 5	+23	+15	+11	+19	− 2	0
+244	+223	+206	+ 87	− 1	− 18	− 14	+ 2	−18	−19	−12	−14	−15
−204	−330	−348	−325	−207	− 44	+ 5	+29	+21	+19	+13	+10	+ 8
+247	+216	+126	− 13	− 83	− 43	− 10	− 9	−24	−16	− 1	+ 8	+ 4
−208	−277	−293	−302	−128	− 12	+ 46	+24	− 2	+ 2	− 1	− 8	− 2
+191	+ 57	−135	−195	−229	−136	− 36	− 1	− 7	−21	−12	− 6	0
− 84	−237	−324	−321	−235	− 58	+ 38	+18	− 2	+11	+ 5	− 1	− 4
+272	+324	+225	+ 83	− 57	−117	− 81	−29	−24	− 7	+12	+ 3	+ 5
+ 65	+ 18	− 38	− 36	−104	− 99	− 63	−67	−35	−27	−15	−14	−13
+287	+302	+228	+ 64	− 42	−136	−152	−86	−77	−38	−17	−18	−12
Sunspot-group "Max₄"												
− 54	− 89	−137	−138	− 79	− 13	+ 20	+ 4	− 7	−13	− 7	− 8	+ 7
+245	+192	+ 86	+ 28	− 12	− 40	− 34	+ 5	−25	−18	−11	+ 7	+12
−148	−149	−189	−145	− 79	− 28	+ 30	+46	+22	+ 8	+ 5	− 4	+ 8
+114	+156	+139	− 39	−120	−144	− 72	−40	−17	−20	−13	− 8	+ 1
−287	−305	−267	−185	− 56	+ 1	+ 28	+23	+ 6	+10	+ 6	+ 4	− 1
+373	+194	− 11	−170	−209	−149	− 43	0	+ 3	+18	+18	0	+ 9
+ 34	− 54	−110	−145	−159	− 58	+ 2	+ 8	+ 6	+ 8	+28	+ 8	+ 7
+476	+439	+266	+ 67	− 40	−104	− 82	−49	−24	−17	−10	−18	0
+121	+ 57	− 84	−148	−119	− 52	− 21	+ 1	+27	+ 7	+11	− 1	− 8
+422	+388	+280	+143	+ 32	− 35	− 37	− 7	+18	−13	−10	−13	+11
Summary by months												
+ 15	− 53	− 94	− 98	− 57	− 5	+ 28	+20	+ 3	+ 9	+14	0	+ 2
+178	+155	+102	+ 33	− 31	− 43	− 35	− 8	−21	−17	−11	+ 1	− 1
−125	−177	−210	−192	−127	− 39	+ 13	+29	+14	+10	+ 7	+ 2	+ 4
+191	+177	+110	− 15	− 83	− 87	− 42	−17	− 9	− 6	− 6	0	+ 2
−221	−260	−256	−205	− 96	− 14	+ 25	+17	− 2	− 2	+ 2	− 1	− 1
+259	+135	− 34	−155	−199	−145	− 58	− 9	− 3	− 6	− 1	− 2	+ 3
+ 14	−120	−209	−228	−190	− 78	+ 6	+17	+ 2	− 3	+ 3	− 1	− 2
+343	+324	+202	+ 41	− 79	−129	− 95	−46	−19	−13	− 6	− 9	− 1
+100	+ 34	− 52	− 85	− 93	− 58	− 23	−11	− 4	− 5	+ 1	− 5	− 3
+247	+262	+189	+ 83	− 6	− 72	− 77	−33	−24	−19	− 9	−12	+ 2
Summary by sunspot-groups and grand average												
− 38	−105	−150	−143	−107	− 45	+ 13	+16	0	0	+ 3	− 3	+ 1
+174	+137	+ 53	− 40	− 93	− 94	− 60	−17	− 4	+ 1	− 1	0	+ 1
+ 5	− 82	+144	−138	− 93	− 25	+ 9	+21	0	0	+ 6	+ 2	− 2
+215	+206	+125	+ 23	− 69	−104	− 77	−33	−21	−25	−17	− 7	0
− 63	−163	−208	−215	−150	− 51	+ 6	+ 5	− 1	+ 3	+ 4	− 3	− 2
+248	+224	+130	+ 5	− 82	− 90	− 59	−25	−30	−20	− 6	− 5	− 4
− 67	−108	−157	−152	− 98	− 30	+ 12	+16	+11	+ 4	+ 9	0	+ 3
+326	+274	+152	+ 6	− 70	− 94	− 54	−18	− 9	−10	− 5	− 6	+ 7
− 44	−116	−165	−163	−113	− 38	+ 10	+14	+ 3	+ 2	+ 6	− 1	0
+243	+210	+114	− 4	− 79	− 95	− 61	−22	−15	−12	− 6	− 4	+ 1

it should also show in a semimonthly wave in the hourly changes δH; and the amplitudes of these waves are found to be less than one per cent of those around noon [4].

Our elimination of the non-cyclic change tends to efface the day-to-day change in the lunar semimonthly wave at 20^h, distributing it over the 24-hour intervals. No correction was found necessary for this negligible effect.

It has been customary to express S and L in hourly means given as deviations from the daily mean; the choice of the night level from which to reckon $\triangle H$ will, however, be found to express certain features of S and L more clearly. Another possibility, namely, to study S and L in the hourly changes δH, was also considered. In the 12 hours of daylight between 06^h and 18^h, the average numerical departures from the night level for S and L stand in the ratio (100 22); but the average changes δH from hour to hour for S and L stand in the approximate ratio (100/33). In other words, L appears, relative to S, greater in the changes δH than in the departures $\triangle H$. This was at first believed to favor a study of $L(M_2)$ and $L(N_2)$ in δH, in preference to $\triangle H$. But statistical computations, applying the principle described in § 21, showed that the standard deviations of the irregular fluctuations in δH, compared with those for $\triangle H$, increase so nearly proportionally to the increase of L relative to S, that it was decided to study L in the departures which, in any case, have the advantage of a simpler physical meaning.

Even for stations and magnetic elements for which L at night may not be so much depressed as at Huancayo in H, it might be favorable to eliminate the spurious ring-current effects by reducing the night level for L to zero, or, in other words, to study not L itself but its deviations from a night level, expecially when $L(N_2)$ or other partial tides are to be considered.

The suppression of L at night in Huancayo H leads to a lunar semimonthly wave in the ordinary daily means of H, described elsewhere [4, § 13].

Sine-waves of frequency 2ν can be interpreted as waves of frequency 2τ of the same amplitude, but with the phase taken negative, apart from a phase-constant depending on t [see the formulas in § 27].

§ 26. *The effect of lunar distance on the tide-producing forces*

The dynamo-theory connects the lunar geomagnetic tides with the lunar semidiurnal tides in the ionosphere, which, in turn, are governed primarily by the tide-producing gravitational forces. At perigee or at apogee, when the Moon is nearest to the Earth or farthest away, these forces, compared with the average, are 18.8 per cent greater or 13.8 per cent smaller.

Strong resonance-phenomena characterize the tides of the air-ocean as inferred from long series of readings of barometric pressure near the ground [1]. However, for a convenient description of the tide-producing forces, the conception of "equilibrium-tides" will be used, that is, the changes of level that would be produced in an ocean of a fluid of very small density covering completely a rigid Earth, if the time-changes were slowed down so that the surface of the fluid would at any time take the shape of an equipotential surface. In this case, the amplitudes of the semidiurnal lunar atmospheric and geomagnetic tides at perigee would

be greater than those at apogee, in the ratio $[(100+18.8)\ (100-13.8)]$, or about (11/8); the phase-angles would be the same.

In calculations based on the *apparent* Moon as given in astronomical year-books, the change of the amplitude from apogee to perigee would be the main influence of the lunar distance. But in the present study, based on the *mean* Moon, a change in the phase-angle of the semidiurnal tides must also be considered. With Chapman, we divide the anomalistic month (or 27.555 days, reckoned from one perigee to the next) into four quarters, one each centered at perigee (PER) and at apogee (APO), and two centered at points between (REC, "receding," between perigee and apogee, and NEA, "nearing"). If s and p are the mean celestial longitudes of the Moon and of the perigee, $(s-p)$ is the Moon's distance from its perigee, completing 360° within an anomalistic month, and the quarters PER, REC, APO, and NEA are centered at $(s-p)=0°$, 90°, 180°, and 270°.

When the Moon is nearer to the Earth it moves faster in its orbit; and since this orbital motion causes the Moon to appear later from day to day, this apparent lag against the Sun is accentuated near perigee (PER) and diminished near apogee (APO). Compared with the evenly moving mean Moon, the apparent Moon loses in the half-month from NEA over PER to REC, and gains in the other half-month. The effects accumulate so that the tide expressed in mean lunar time τ will appear most retarded at REC $[(s-p)=90°$ or 6 hours$]$ and most accelerated at NEA $[(s-p)=270°$ or 18 hours$]$. The transit-times given in Table 4 illustrate this remark. A particularly large difference will be noticed in Table 4 for January 29, 1935, when the mean Moon culminates more than three-quarters of an hour before the apparent Moon; about this date, the complicated motion of the apparent Moon differed, in fact, from that of the mean Moon even more than can be accounted by the influence of the partial tides discussed below.

§ 27. *The partial tides expressing the effect of lunar distance*

The classical harmonic analysis of the tidal forces [8 and 9] expresses the influence of the lunar distance by a superposition of partial tides, sine-waves of constant amplitudes, and different frequencies, and designated by standard symbols. It considers two time-variables, both progressing at an even rate, namely, mean lunar time τ and the mean Moon's distance $(s-p)$ from its perigee. The function giving the geographical distribution is the same for the semidiurnal partial tides; and since it is appropriate in our case to consider the partial tides relative to the main tide M_2 (expressing the effect of the mean Moon at constant mean distance), the relevant partial tides at any locality may be written.

$$\left.\begin{array}{l} M_2=100.00 \cos 2\tau, \text{ period } 12.4206 \text{ solar hours} \\ N_2=19.15 \cos [2\tau-(s-p),] \text{ period } 12.6583 \text{ solar hours} \\ L_2=-2.83 \cos [2\tau+(s-p)], \text{ period } 12.1916 \text{ solar hours} \\ 2N=+2.53 \cos [2\tau-2(s-p)], \text{ period } 12.9054 \text{ solar hours} \end{array}\right\} \quad (27.1)$$

Written in the standard form [amplitude, phase] of lunar semidiurnal sine-waves,

$$M_2\equiv[100.00, 90°] \quad N_2\equiv[19.15, 90°-(s-p)] \quad L_2=-[2.83, 270°+(s-p)]$$
$$2N=[2.53, 90°-2(s-p)] \qquad (27.2)$$

In a harmonic dial for lunar semidiurnal sine-waves, M_2 is a constant vector of length 100 pointing upward; the vector N_2, of length 19.15 points upward for perigee and its end-point describes a circle clockwise within an anomalistic month; the vector L_2, of length 2.83, points downward at perigee and describes a circle counterclockwise; the vector $2N$, of length 2.53, points upward and describes twice a circle clockwise

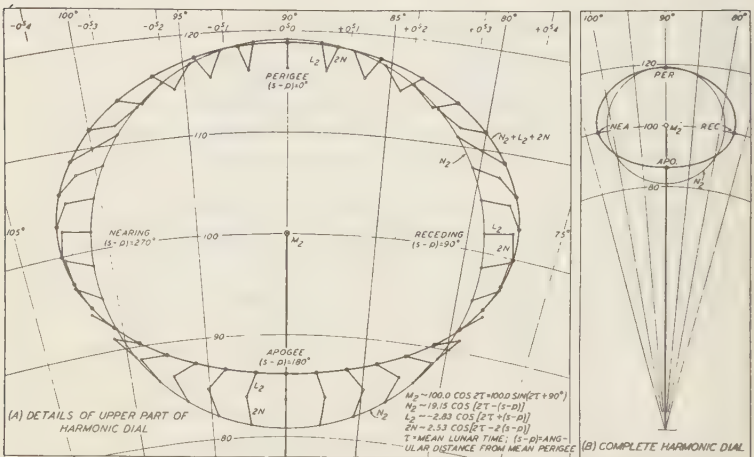


FIG. 12—HARMONIC DIAL FOR LUNAR SEMIDIURNAL WAVES IN GRAVITY-POTENTIAL SHOWING INFLUENCE OF LUNAR DISTANCE; PARTIAL TIDES N_2, L_2, 2N SUPERPOSED ON MAIN TIDE M_2

within an anomalistic month. Figure 12 pictures the successive stages of superposition up to $(M_2+N_2+L_2+2N)$ for 36 intervals throughout the anomalistic month. At REC the combined lunar semidiurnal wave comes nearly half an hour later than M_2, and at NEA nearly half an hour earlier than M_2.

Our previous discussion ignored partial tides other than M_2 by averaging without regard to the perigee. Just as the main tide M_2 in the tidal forces, by way of the tidal motions in the ionosphere, produces a geomagnetic tide L—more specifically to be designated as $L(M_2)$— each of the other partial tides produces geomagnetic tides $L(N_2)$, $L(L_2)$, and $L(2N)$. Because of the linearity of the equations connecting the air-velocities, the electromotive forces, and the ionospheric currents and their geomagnetic effects, these various geomagnetic partial tides can be assumed to be superposed without mutual interaction; our computations will be arranged according to this assumption.

§ 28. *Prospects of determining geomagnetic effects of lunar distance*

All geomagnetic partial tides are essentially sine-waves. The problem is to obtain, from a limited number of observations, the most accurate expression for each sine-wave, so that the ratio (ρ/c) —probable-error circle radius ρ for the average wave, of amplitude c, say—is as small as possible. If again, as in § 15, ρ_0 is the probable-error circle radius for waves computed from single calendar months, average sine-waves

computed from n months yield $\rho=(\rho_0/\sqrt{n})$. If, then, two different partial tides, L' and L'', say, shall be computed with the same accuracy, this requires $(\rho'/c')=(\rho''/c'')$, or

$$(n'/n'')=[(\rho_0'/\rho_0'')(c''/c')]^2 \tag{28.1}$$

If L' is identified, in succession, with $L(N_2)$, $L(L_2)$ and $L(2N)$, and L'' with $L(M_2)$, if, furthermore, $\rho_0'=\rho_0''$, and if (c''/c') stand in the ratios of the tidal forces, we obtain $(n'/n'')=27$ for N_2, 125 for L_2, 156 for $2N$. In other words, even for N_2, more than two years of data are necessary to obtain the same accuracy as one calendar month gives for M_2; in the case of L_2, the whole series of observations, 212 months, will not yield the same accuracy as two months do in the case of M_2.

In the case of N_2 the prospects will become somewhat brighter since $L(N_2)$ will be found to have a relatively larger amplitude 30.4 per cent of that of $L(M_2)$. On the other hand, there is an influence which may increase ρ_0 and thereby further reduce the relative accuracy. While, namely, the main term $L(M_2)$ performs a series of cycles with respect to S within half a (synodic) month, $L(N_2)$ requires a full (anomalistic) month for completing a series of cycles with respect to $L(M_2)$; in other words, N_2 depends on the contrast of L on days half a month apart, which makes it more vulnerable to spurious effects caused by the variability of S, with its quasi-persistent 27-day recurrence-tendency. The same recurrence-tendency in disturbances will often make necessary the elimination, as disturbed, of days with the same value of $(s-p)$, which makes the distribution of the remaining days with respect to $(s-p)$ more uneven [Ad. Schmidt, 17].

The separation of S, $L(M_2)$, and $L(N_2)$ depends essentially on the differences of the time-variables of the semidiurnal waves, which are $2t$, $(2t-2\nu)$, and $[2t-2\nu-(s-p)]$. In semimonthly waves, $L(M_2)$ and $L(N_2)$ have the frequencies of 2ν and $[2\nu+(s-p)]$. $2t$ completes a cycle every half-day; an effective separation depends therefore on a sufficient number of days for each possible combination of 2ν and $(s-p)$. Because the synodic and the anomalistic months differ little, each calendar month gives essentially only one combination of $L(M_2)$ and $L(N_2)$, described by the age ν_{PER} at the day of perigee $(s-p)=0$ [Ad. Schmidt, 17]. Within an average year of 365.25 days, ν_{PER} increases by an average 2.71 hours. Since the seasonal variation of L forces restriction of each individual computation to calendar months, this means that, for instance ν_{PER} for January, 1938, and January, 1939, differs by only 2.7 hours. Tables 13 and 14 gave a good example.

§ 29. *Partial tides relative to main tide*

The considerations in § 28 show that the distance-effects can be ascertained only in the average for a large mass of material. Now, all semidiurnal partial geomagnetic tides, according to the dynamo-theory, will depend on the air-motion (v, say) and the ionization (I, say). The ionization varies with solar time in the day, and with the season and sunspot-cycle, but is independent of the Moon. The ionospheric air-motions v have for all semidiurnal tides nearly the same geographical distribution with respect to latitude and to longitude reckoned from a zero-meridian which may be different for each partial tide whatever the resonance-

conditions may be, and their periods are so nearly alike that, on any particular day, they superpose to one semidiurnal tide characterized by *one* amplitude v and *one* phase-angle β of a lunar semidiurnal sine-wave. Induction of the Earth's vertical magnetic force component produces, from this air-motion, a distribution of electromotive forces, likewise characterized by two parameters which stand in fixed relations to v and ϵ. The geographical distribution of the ionization regulates the ionospheric currents which, finally, produce the sine-waves in H at Huancayo. This leads to the general formula

$$\left.\begin{aligned} L &= f(t)v \sin [2(t-\nu)+\epsilon(t)+\beta] \quad \text{or} \\ L &= \text{real part of } f(t)\, v \exp \{i[2(t-\nu)+\epsilon(t)+\beta-90°]\} \end{aligned}\right\} \qquad (29.1)$$

$f(t)$ and $\epsilon(t)$ express the *combined* influences of the dynamo-theory transformations

Air-motion→induced electromotive forces→electric currents→ magnetic effects

from the purely semidiurnal tidal air-motions into the geomagnetic tides produced by them; according to our discussion we may assume that $f(t)$ and $\epsilon(t)$ are *the same for each partial tide.*

For the tides M_2 and N_2, for instance, β is to be replaced by $\beta(M_2)$ and $[\beta(N_2)-(s-p)]$, and

$$\left.\begin{aligned} L(M_2) &= f(t)v(M_2) \exp \{i[2(t-\nu)+\epsilon(t)+\beta(M_2)-90°]\} \\ L(N_2) &= f(t)v(N_2) \exp \{i[2(t-\nu)+\epsilon(t)-(s-p)+\beta(N_2)-90°]\} \end{aligned}\right\} \qquad (29.2)$$

Consequently

$$L(N_2)=L(M_2)\times[v(N_2)/v(M_2)] \exp \{i[\beta(N_2)-\beta(M_2)-(s-p)]\} \qquad (29.3)$$

The usual geometrical representation of complex quantities by plane vectors interprets this equation as follows: From the vector for $L(M_2)$, the vector for $L(N_2)$ is obtained by reducing the amplitude in the ratio $[v(N_2)/v(M_2)]$, and by adding $[\beta(N_2)-\beta(M_2)-(s-p)]$ to the phase-angle.

In the harmonic dial for lunar semidiurnal sine-waves—which, of course, is essentially such a representation of complex quantities—this may be expressed as follows: For a fixed solar time t, we introduce a new unit for amplitudes, and lunar time τ' differing from τ by another time-origin, such that $L(M_2)$ becomes

$$L(M_2) \equiv 100 \sin (2\tau'+90°) \qquad (29.4)$$

Then, for the same solar time t, in the same system of amplitude and time

$$L(N_2) \equiv \gamma(N_2) \sin [2\tau'+\eta(N_2)-(s-p)] \qquad (29.5)$$

This new way of expressing $L(N_2)$ relative to $L(M_2)$, by an amplitude $\gamma(N_2)$ in per cent of that of $L(M_2)$, and a phase-angle-difference $[\eta(N_2)-90°]$ is, of course, quite general and can be applied independently of any theory. If the dynamo-theory, in its simple form outlined above, is valid, $\gamma(N_2)$ and $\eta(N_2)$ are independent of the time t of the day, namely

$$\gamma(N_2)=100[v(N_2)/v(M_2)] \qquad \eta(N_2)=[90°+\beta(N_2)]-\beta(M_2) \qquad (29.6)$$

The method is designed to reduce the statistical scattering due to changes in the ionization, because it will affect the partial tides in the same way as M_2, and allows one also to combine results for different seasons and stages of solar activity.

For $L(L_2)$, the phase-angle added to $(2\tau'+90°)$ in (29.5) is $[\eta(L_2)+(s-p)]$ and for $L(2N)$, it is $[\eta(2N)-2(s-p)]$.

For the tidal forces, the relative amplitudes and phase-angles of the partial tides were given in (27.2).

The formal transition from lunar semidiurnal waves, of frequency 2τ, to lunar semimonthly waves, of frequency $2\nu=2(2t-2\tau)$, reverses the additional phase-angles, such as β or η, that is, changes β into $(2\pi-\beta)$; this is important and can be easily visualized as shown elsewhere [12].

§ 30. *Preliminary results on distance-effects based on ranges A*

Lunar distance-effects on horizontal intensity based upon an analysis of the ranges A were reported in [4]. Figure 13, utilizing the latest computed values, shows the results for the months September to April, 1922-39. The observed tides in the four quarters are shown with their

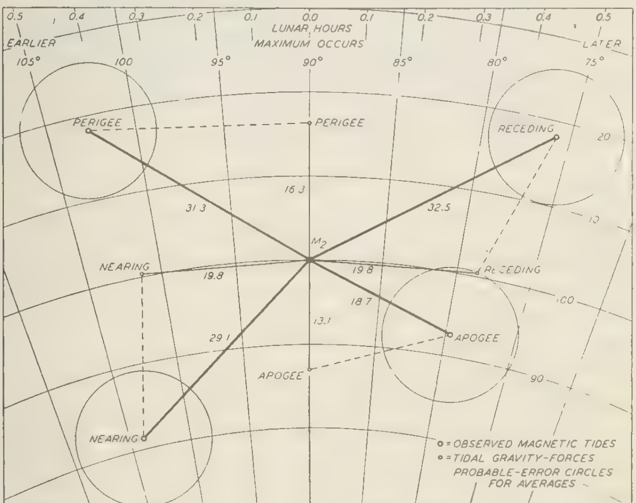


FIG. 13—EFFECT OF LUNAR DISTANCE ON GEOMAGNETIC TIDES IN HORIZONTAL FORCE, HUANCAYO, SEPTEMBER TO APRIL, 1922-39; HARMONIC DIAL SHOWING AVERAGE LUNAR SEMIDIURNAL WAVES ADDITIVE TO MAIN TERM M_2, FOR FOUR QUARTERS OF ANOMALISTIC MONTH

probable-error circles and they are to be compared with the quarterly "theoretical" averages computed from Figure 12. Obviously the observed influence of lunar distance is quite marked, but it differs in character from the simple "theoretical" relationship in the tidal forces. The main change of the lunar semidiurnal wave from PER to APO is not (as in the "theoretical" case) a decrease in amplitude, but a shift in the phase-angle of the lunar semidiurnal wave, the maximum at APO occurring 0.9 hour later than at PER. This agrees qualitatively with Chapman's results for other observatories and supplements them with reference to the

well-known partial tides of the tidal forces; Chapman's early calculations did not permit this reference since they are based on apparent lunar time, the lunar transits being taken from the *Astronomical Year Book*. While the "theoretical" change of the lunar semidiurnal wave from REC to NEA is merely an acceleration, the "observed" change is a decrease in amplitude from 127 to 76 units. In all the "observed cross" expressing L in the four quarters is obtained from the "theoretical cross" expressing the tidal forces by enlarging the theoretical cross and turning it toward the left by nearly a quarter-month.

The four results for the quarter-months allow a separation into the four partial tides, M_2, N_2, L_2, $2N$. Figure 14 shows, at the left, how in-

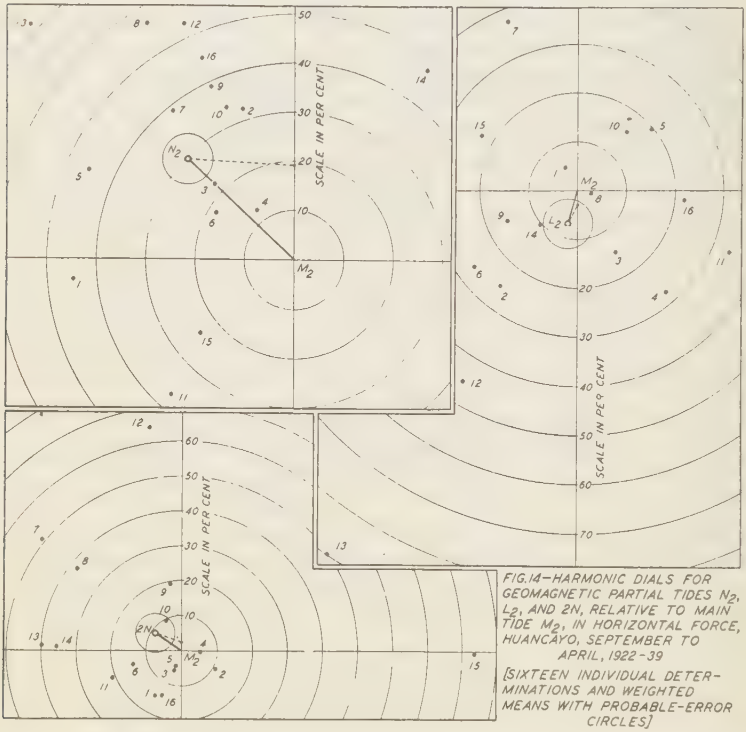


FIG. 14—HARMONIC DIALS FOR GEOMAGNETIC PARTIAL TIDES N_2, L_2, AND 2N, RELATIVE TO MAIN TIDE M_2, IN HORIZONTAL FORCE, HUANCAYO, SEPTEMBER TO APRIL, 1922-39

[SIXTEEN INDIVIDUAL DETERMINATIONS AND WEIGHTED MEANS WITH PROBABLE-ERROR CIRCLES]

dividual results for N_2 were combined with weights according to the absolute amplitude of the main term, and, at the right, final total averages for the partial geomagnetic tides relative to M_2. Only N_2 is determined with certainty, its probable-error circle being less than one-seventh of its amplitude. If the main term is put equal to

$$M_2 = 100.0 \sin (2\tau + 90°) \tag{30.1}$$

in the ("theoretical") tidal forces and

$$M_2 = 100.0 \sin (2\tau + 90° + \triangle \epsilon) \tag{30.2}$$

in the observed geomagnetic tides (with $\triangle\epsilon$ varying with the season, being $(216°-90°)=126°$ in the average for December, January, and February), the "theoretical" partial tide in the tidal forces is

$$N_2=19.1 \sin [2\tau+90°-(s-p)] \tag{30.3}$$

to be compared to observed geomagnetic partial tide

$$N_2=31.4 [2\tau+90°-(s-p)+\triangle\epsilon+56°] \tag{30.4}$$

with a probable-error circle of 5.2 units.

Of special interest is the fact that N_2, with its period of 12.658 hours, is apparently stronger in the ionosphere than M_2 with its period of 12.421 hours. On the basis of the old theories which considered only one resonance-period for each type of oscillations of the atmosphere as a whole, it was necessary to assume this period to be near 12.0 hours, in order to explain the large magnification of the solar semidiurnal tide; but then it would be hardly explicable why N_2 should be relatively more magnified than M_2, although the frequency of N_2 is farther away from the resonance-period. G. I. Taylor's new theory of multiple resonance-periods, however, removes this difficulty. The fact that the M_2-wave apparently swings in the ionosphere in opposite direction to the lower atmosphere should also be considered. New approaches to this problem seem necessary by reduction of observations as well as by theory. One result seems certain, namely, compared with the winds near the ground, the atmospheric motions in the lower ionosphere are much more dominated by tides.

§ 31. *Computation of* $L(N_2)$

The computation of the main distance-term will be described for the group January Min$_1$, for which the distribution of days has been given in Tables 13 and 14. It consists mainly in the successive computation of matrices similar to those tables in which the elements are number of days (as in Tables 13 and 14) or sine-values or sums of observed hourly changes etc., and in the formation of product-sums of two tables, each element in one table being multiplied with the element in the corresponding place in the other table. Some of these tables will be "permanent," giving standard factors, others will be "exemplary" for the group January Min$_1$ considered; it was thought better to describe the procedure in an example (Tables 16-*A* to 16-*Q*) instead of in general terms involving a formidable number of indices. A knowledge of the paper by Chapman and Miller [3] will be helpful to the reader because many points are similar; but there are differences which will be pointed out in § 33. The successive steps will be described by reference to tables; the "permanent" tables are so marked.

Table 16-A- Group-sums for the two-fold differences, for 48 groups as in Table 14.

Table 16-B—Condensation of the essential parts of Table 16-*A* as follows: Four three-hourly changes are formed for each day by addition of three (horizontally) successive differences, namely, 05^h-06^h to 08^h-09^h to 11^h-12^h to 14^h-15^h to 17^h-18^h, standard 75° west meridian time. The rows with $(s-p)=4$, 5, 6, and 7 are *subtracted* from those with $(s-p)=$ 0, 1, 2, and 3 since $(s-p)$ changes from $(s-p)=0$ to $(s-p)=4$ by 180°. Thus from Table 16-*A*, for January Min$_1$ from 05^h-06^h to 08^h-09^h, $\nu=0$, $[(s-p)=0]-[(s-p)=4]$, we have the two-fold difference

TABLE 16—*Specimen computations for $L(N_2)$ in horizontal intensity at Huancayo Magnetic Observatory for January Min_1 sunspot-group, 1922-39*

TABLE 16-*A*—*Group-sums two-fold differences for January Min_1 sunspot-group for $\nu=0$ for values of $(s-p)=0$, 1, 2, 3, 4, 5, 6, and 7 for days given in Table 14*

$(s-p)$	Changes in gammas at 75° west meridian hours												
	20	21	22	23	00	01	02	03	04	05	06	07	08
0	+26	− 5	+ 3	+ 6	+ 9	+ 7	0	− 9	− 7	− 2	− 1	− 6	−10
4	+10	−23	− 3	+10	+ 1	+10	+ 2	−21	+ 6	+ 9	+ 7	+ 3	−34
1	−14	0	+ 1	− 3	− 5	+ 9	+ 5	+ 6	+ 8	− 5	+ 5	+14	+29
5	−11	0	+18	+16	− 5	− 5	− 6	+ 3	− 7	− 7	− 1	+ 1	+23
2	−10	− 3	− 4	− 3	+20	+12	−10	− 3	− 1	− 1	−16	−25	−18
6	+ 5	+ 3	− 6	− 1	+ 3	+ 4	+ 3	+ 5	+ 4	− 2	+25	+28	+50
3	+ 7	−17	+11	− 3	− 4	+ 3	0	− 4	− 6	+ 2	+17	+44	+10
7	+ 2	+ 4	+ 3	+ 1	+ 5	− 3	0	− 2	+ 5	− 7	+ 1	− 2	+ 2

$(s-p)$	Changes in gammas at 75° west meridian hours											Totals	
	09	10	11	12	13	14	15	16	17	18	19	Non-cyclic	06h-17h
0	+ 9	+11	−24	−22	+11	−21	− 9	+13	+27	+14	+11	+31	−22
4	−25	−34	− 7	−33	+20	+ 4	+47	+36	+ 2	+ 6	+15	+ 8	−14
1	+16	− 8	+22	−29	+14	− 5	−13	−21	−23	+ 1	−12	− 8	+ 1
5	+ 4	+46	−17	− 2	−35	−11	−17	+ 9	+ 5	− 2	+12	−11	+ 5
2	+25	− 8	−52	− 5	−16	+47	+ 8	+52	+35	−27	+14	+11	+27
6	+20	−37	−56	−96	−69	+ 6	+39	+18	+35	+12	− 7	−14	−37
3	+18	− 4	− 8	−12	−28	+19	− 8	+13	−30	−18	− 7	− 5	+31
7	+ 1	−14	−21	− 5	− 7	−11	+ 1	+28	+12	+ 7	+11	+11	−15

Note: Group-sums for $\nu=1$, 2, 3, 4, and 5, used in later computations are not tabulated in text.

$(-1\ -6\ -10)-(+7\ +3\ -34)=+7\gamma$. For each of the four changes per day, $L(N_2)$ is determined separately, but the calculation is conveniently made in parallel. The values in Table 16-*B* will be referred to later as $f[\nu,(s-p)]$.

Table 16-C—Number $n_N[\nu,(s-p)]$ of days in each sum in Table 16-*B*, obtained by adding the numbers in Table 14 for $[(s-p)=0]+[(s-p)=4]$, . . . 1+5, 2+6, 3+7. Valid for $L(N_2)$.

Table 16-D—Number $n_M[\nu,(s-p)]$, valid for $L(M_2)$, which is independent of $(s-p)$, obtained by *subtracting* the numbers in Table 14, $[(s-p)=0]-[(s-p)=4]$, etc.

Tables 16-E to *16-J*, (permanent)—Angles $[2\nu+(s-p)]$, cosines and sines of these angles, their squares and products.

Tables 16-K, *16-L*, *16-M*—Products of Table 16-*C* with Tables 16-*H*, 16-*I*, 16-*J*; only the product-sums of Tables 16-*K*, 16-*L*, 16-*M* (lower right-hand corner) are used further.

Tables 16-N, *16-O*—Products of Table 16-*D* with Tables 16-*F* and

16-*G*, further multiplied with cos 2ν and sin 2ν; only the product-sums are used.

Tables 16-P, 16-Q—Products of Table 16-*B* with Tables 16-*F* and 16-*G*, and sums with sums of products $\nu=0, +1+\ldots+5$, for instance, $-24, +64, -23, +37, +36, +22=+112$. Only these are used further.

The average two-fold change from one preceding day up to a day in the group $(\nu, s-p)$ may be

$$a(M_2)\cos 2\nu+b(M_2)\sin 2\nu \quad \text{for } L(M_2) \tag{31.1}$$

$$a(N_2)\cos[2\nu+(s-p)]+b(N_2)\sin[2\nu+(s-p)] \quad \text{for } L(N_2) \tag{31.2}$$

For the sums $f[\nu, (s-p)]$ in Table 16-*B*, therefore, which are the sums of (31.1) and (31.2), each group-sum yields one equation which is the sum of $n_N[\nu, (s-p)]$ individual equations (one for each day-to-day change), namely

$$\begin{aligned} a(N_2)\, n_N[\nu, (s-p)]\cos[2\nu+(s-p)]+b(N_2)\, n_N[\nu, (s-p)]\sin[2\nu+(s-p)] \\ =f[\nu, (s-p)]-a(M_2)\, n_M(\nu, s-p)\cos 2\nu-b(M_2)\, n_M[\nu, (s-p)]\sin 2\nu \end{aligned} \tag{31.3}$$

$a(M_2)$ and $b(M_2)$ are supposed to be known; they can be derived from the calculation in § 24, as shown below. In all then, we have $\Sigma n_N[\nu, (s-p)]$ (the sum Σ over all values in Table 16-*C*) linear equations to be solved

TABLE 16-*B*—*Summary of $f[\nu, (s-p)]$ for three-hour intervals during daylight 06ʰ to 17ʰ*

)a	Three-hourly changes in gammas for 75° west meridian hours														
p)b	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum
b	For $\nu=0$					For $\nu=1$					For $\nu=2$				
4	+7	+62	−23	−54	−8	+2	−26	−10	+30	−4	−15	+81	−96	+35	+5
5	+25	−3	+28	−54	−4	+42	+95	−72	−47	+18	−68	−133	+211	−29	−19
6	−162	+38	+185	+3	+64	−15	−12	−49	+50	−26	+19	+34	−52	+31	+32
7	+70	+40	+2	−66	+46	−44	+20	+128	−104	0	+18	+35	−93	+9	−31
	For $\nu=3$					For $\nu=4$					For $\nu=5$				
4	+21	−4	−1	−38	−22	−8	−86	−17	+103	−8	−7	+4	+68	−104	−39
5	−3	+75	0	+32	+104	−9	−166	+123	+49	−3	+8	+143	+5	−119	+37
6	−17	+27	+38	−15	+33	−23	+98	−44	−42	−11	−38	−109	+116	+49	+18
7	−26	+60	+59	−58	+35	−10	−18	+58	−57	−27	+20	−63	+63	+19	+39

TABLE 16-*C*

)a	$n_N[\nu, (s-p)]$ for $\nu=$						Sum
-p)b	0	1	2	3	4	5	
b							
4	6	2	3	2	5	4	22
5	5	9	5	6	6	6	37
6	6	3	3	1	3	10	26
7	5	6	5	5	3	5	29
n	22	20	16	14	17	25	114

TABLE 16-*D*

$(s-p)_a$ $-(s-p)_b$	$n_M[\nu, (s-p)]$ for $\nu=$						Sum
	0	1	2	3	4	5	
a b							
0 4	+2	−2	+1	0	−3	−2	−4
1 5	−1	−1	+1	−2	−2	+2	−3
2 6	0	+1	−1	−1	+1	−4	−4
3 7	+1	0	+1	−1	−1	+1	+1
Sum	+2	−2	+2	−4	−5	−3	−10

TABLES 16-*E*, 16-*F*, 16-*G*, 16-*H*, 16-*I*, 16-*J*—*Angles* $[2\nu+(s-p)]$, *cosines and sines of these angles, their squares and products (these Tables are permanent)*

$(s-p)$	Table 16-*E* Angles, $[2\nu+(s-p)]$ For $\nu=$ 0	1	2	3	4	5	Table 16-*F* $\cos[2\nu+(s-p)]$ For $\nu=$ 0	1	2	3	4	5
	°	°	°	°	°	°						
0	0	30	60	90	120	150	+1.000	+0.866	+0.500	0.000	−0.500	−0.8
1	45	75	105	135	165	195	+0.707	+0.259	−0.259	−0.707	−0.966	−0.9
2	90	120	150	180	210	240	0.000	−0.500	−0.866	−1.000	−0.866	−0.5
3	135	165	195	225	255	285	−0.707	−0.966	0.966	−0.707	−0.259	+0.

$(s-p)$	Table 16-*G* $\sin[2\nu+(s-p)]$ For $\nu=$ 0	1	2	3	4	5	Table 16-*H* $\cos^2[2\nu+(s-p)]$ For $\nu=$ 0	1	2	3	4	5
0	0.000	+0.500	+0.866	+1.000	+0.866	+0.500	1.00	0.75	0.25	0.00	0.25	0
1	+0.707	+0.966	+0.966	+0.707	+0.259	−0.259	0.50	0.07	0.07	0.50	0.93	0.
2	+1.000	+0.866	+0.500	0.000	−0.500	−0.866	0.00	0.25	0.75	1.00	0.75	0.
3	+0.707	+0.259	−0.259	−0.707	−0.966	−0.966	0.50	0.93	0.93	0.50	0.07	0.

$(s-p)$	Table 16-*I* $\sin^2[2\nu+(s-p)]$ For $\nu=$ 0	1	2	3	4	5	Table 16-*J* $\cos[2\nu+(s-p)]\sin[2\nu+(s-p)]$ For $\nu=$ 0	1	2	3	4	5
0	0.00	0.25	0.75	1.00	0.75	0.25	0.00	+0.43	+0.43	0.00	−0.43	−0
1	0.50	0.93	0.93	0.50	0.07	0.07	+0.50	+0.25	−0.25	−0.50	−0.25	+0.
2	1.00	0.75	0.25	0.00	0.25	0.75	0.00	−0.43	−0.43	0.00	+0.43	+0.
3	0.50	0.07	0.07	0.50	0.93	0.93	−0.50	−0.25	+0.25	+0.50	+0.25	−0.

for the two unknowns $a(N_2)$, $b(N_2)$. The least-square method gives essentially the same solution as the method called "preservation" by Chapman and Miller [3]; the two "normal equations" become, with sums extending over the 24 groups in Tables 16-*B*, 16-*C*, or 16-*D*

$$\begin{aligned} a(N_2)\Sigma n_N[\nu,(s-p)]\cos^2[2\nu+(s-p)]+&\\ b(N_2)\Sigma n_N[\nu,(s-p)]\cos[2\nu+(s-p)]\sin[2\nu+(s-p)]&\\ =\Sigma f[\nu,(s-p)]\cos[2\nu+(s-p)]-a(M_2)\Sigma n_M[\nu,(s-p)]\cos 2\nu\cos[2\nu+(s-p)]&\\ -b(M_2)\Sigma n_M[\nu,(s-p)]\sin 2\nu\cos[2\nu+(s-p)]& \end{aligned} \quad (31.4)$$

$$\begin{aligned} a(N_2)\Sigma n_N[\nu,(s-p)]\cos[2\nu+(s-p)]\sin[2\nu+(s-p)]+&\\ b(N_2)\Sigma n_N[\nu,(s-p)]\sin^2[2\nu+(s-p)]&\\ =\Sigma f[\nu,(s-p)]\sin[2\nu+(s-p)]-a(M_2)\Sigma n_M[\nu,(s-p)]\cos 2\nu\sin[2\nu+(s-p)]&\\ -b(M_2)\Sigma n_M[\nu,(s-p)]\sin 2\nu\,[2\nu+(s-p)]& \end{aligned} \quad (31.5)$$

The sums occurring in (31.4) and (31.5) have been calculated in Tables 16-*K*, 16-*L*, 16-*M*, 16-*N*, 16-*O*, 16-*R*, 16-*S*; it remains to calculate $a(M_2)$

and $b(M_2)$ from the results for $L(M_2)$ of § 24. We take, for instance, the change of $L(M_2)$ from 11^h-12^h to 14^h-15^h, which, at $2\nu=2°.8$ is $+13.4\gamma$, and, at $2\nu=92°.8$ is -39.0γ. The semimonthly wave is therefore

$$41.2\gamma \sin(2\nu+161°.0-2°.8)=41.2\gamma \sin(2\nu+158°.2)$$

For averages for intervals of width $2\nu=30°$—which are used throughout the $L(N_2)$-calculation—the amplitude is smaller in the ratio ($\sin 15°/\text{arc } 15°$) $=0.99$, that is, 40.8γ. $a(M_2)$ and $b(M_2)$ are then the changes of the wave

$$40.8\gamma \sin(2\nu+158°.2)$$

TABLE 16-*K*

$)_a$ $p)_b$	(Table 16-*C*)×(Table 16-*H*) for ν=						Sum
	0	1	2	3	4	5	
b							
4	6.0	1.5	0.8	0.0	1.2	3.0	12.5
5	2.5	0.6	0.4	3.0	5.6	5.6	17.7
6	0.0	0.8	2.2	1.0	2.2	2.5	8.7
7	2.5	5.6	4.6	2.5	0.2	0.4	15.8
n	11.0	8.5	8.0	6.5	9.2	11.5	54.7

TABLE 16-*L*

$(s-p)_a$ $+(s-p)_b$	(Table 16-*C*)×(Table 16-*I*) for ν=						Sum
	0	1	2	3	4	5	
a b							
0 4	0.0	0.5	2.2	2.0	3.8	1.0	9.5
1 5	2.5	8.4	4.6	3.0	0.4	0.4	19.3
2 6	6.0	2.2	0.8	0.0	0.8	7.5	17.3
3 7	2.5	0.4	0.4	2.5	2.8	4.6	13.2
Sum	11.0	11.5	8.0	7.5	7.8	13.5	59.3

TABLE 16-*M*

$(s-p)_a$ $+(s-p)_b$	(Table 16-*C*)×(Table 16-*J*) for ν=						Sum
	0	1	2	3	4	5	
a b							
0 4	0.00	+0.86	+1.29	0.00	−2.15	−1.72	−1.72
1 5	+2.50	+2.25	−1.25	−3.00	−1.50	+1.50	+0.50
2 6	0.00	−1.29	−1.29	0.00	+1.29	+4.30	+3.01
3 7	−2.50	−1.50	+1.25	+2.50	+0.75	−1.25	−0.75
Sum	0.00	+0.32	0.00	−0.50	−1.61	+2.83	+1.04

TABLE 16-*N*

$)_a$ $p)_b$	(Table 16-*D*)×(Table 16-*F*) for ν=						Sum
	0	1	2	3	4	5	
b							
4	+2.0	−1.7	+0.5	0.0	+1.5	+1.7	+4.0
5	−0.7	−0.3	−0.3	+1.4	+1.9	−1.9	+0.1
6	0.0	−0.5	+0.9	+1.0	−0.9	+2.0	+2.5
7	−0.7	0.0	−1.0	+0.7	+0.3	+0.3	−0.4
n	+0.6	−2.5	+0.1	+3.1	+2.8	+2.1	+6.2
× 2ν	+0.6	−2.2	0.0	0.0	−1.4	−1.8	−4.8
× 2ν	0.0	−1.2	+0.1	+3.1	+2.4	+1.0	+5.4

TABLE 16-*O*

$(s-p)_a$ $-(s-p)_b$	(Table 16-*D*)×(Table 16-*G*) for ν=						Sum
	0	1	2	3	4	5	
a b							
0 4	0.0	−1.0	+0.9	0.0	−2.6	−1.0	−3.7
1 5	−0.7	−1.0	+1.0	−1.4	−0.5	−0.5	−3.1
2 6	0.0	+0.9	−0.5	0.0	−0.5	+3.5	+3.4
3 7	+0.7	0.0	−0.3	+0.7	+1.0	−1.0	+1.1
Sum	0.0	−1.1	+1.1	−0.7	−2.6	+1.0	−2.3
Sum× cos 2ν	0.0	−1.0	+0.6	0.0	+1.3	−0.9	0.0
Sum× sin 2ν	0.0	−0.6	+1.0	−0.7	−2.3	+0.5	−2.1

TABLE 16-*P*

$(s-p)_a$ $-(s-p)_b$	(Table 16-*B*)×(Table 16-*F*)													
	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17
a *b*	For $\nu=0$					For $\nu=1$					For $\nu=2$			
0 4	+ 7	+ 62	−23	−54	− 8	+ 2	− 22	− 9	+ 26	− 3	− 8	+ 40	− 48	+ 18
1 5	+18	− 2	+20	−38	− 2	+11	+ 25	− 19	− 12	+ 5	+18	+ 34	− 54	+ 8
2 6	0	0	0	0	0	+ 8	+ 6	+ 24	− 25	+13	−16	− 29	+ 45	− 27
3 7	−49	− 28	− 1	+47	− 31	+43	− 19	−124	+100	0	−17	− 34	+ 90	− 9
Sum	−24	+ 32	− 4	−45	− 41	+64	− 10	−128	+ 89	+15	−23	+ 11	+ 33	− 10
	For $\nu=3$					For $\nu=4$					For $\nu=5$			
0 4	0	0	0	0	0	+ 4	+ 43	+ 9	− 52	+ 4	+ 6	− 3	− 59	+ 90
1 5	+ 2	− 53	0	−23	− 74	+ 9	+160	−119	− 47	+ 3	− 8	−138	− 5	+115
2 6	+17	− 27	−38	+15	− 33	+20	− 85	+ 38	+ 36	+ 9	+19	+ 54	− 58	− 24
3 7	+18	− 42	−42	+41	− 25	+ 3	+ 5	− 15	+ 15	+ 8	+ 5	− 16	+ 16	+ 5
Sum	+37	−122	−80	+33	−132	+36	+123	− 87	− 48	+24	+22	−103	−106	+186
						Sum $\nu=0$, 1, 2, 3, 4, and 5								
....	......	......	......	......	.....	+112	−69	−372	+205	−124	......	......	......	......

TABLE 16-*Q*

$(s-p)_a$ $-(s-p)_b$	(Table 16-*B*)×(Table 16-*G*)													
	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum	06, 07, 08	09, 10, 11	12, 13, 14	15, 16, 17	Sum	06, 07, 08	09, 10, 11	12, 13, 14	15, 16 17
a *b*	For $\nu=0$					For $\nu=1$					For $\nu=2$			
0 4	0	0	0	0	0	+ 1	− 13	− 5	+ 15	− 2	−13	+ 70	− 83	+30
1 5	+ 18	− 2	+ 20	−38	− 2	+40	+ 91	−69	− 45	+17	−66	−129	+204	−28
2 6	−162	+38	+185	+ 3	+64	−13	− 10	−42	+ 43	−22	+10	+ 17	− 26	+15
3 7	+ 49	+28	+ 1	−47	+31	−11	+ 5	+33	− 27	0	− 5	− 9	+ 24	− 2
Sum	− 95	+64	+206	−82	+93	+17	+ 73	−83	− 14	− 7	−74	− 51	+119	+15
	For $\nu=3$					For $\nu=4$					For $\nu=5$			
0 4	+ 21	− 4	− 1	−38	−22	− 7	− 74	−15	+ 89	− 7	− 4	+ 2	+ 34	−52
1 5	− 2	+53	0	+23	+74	− 2	− 43	+32	+ 13	0	− 2	− 37	− 1	+31
2 6	0	0	0	0	0	+12	− 49	+22	+ 21	+ 6	+33	+ 94	−100	−43
3 7	+ 18	−42	− 42	+41	−25	+10	+ 17	−56	+ 55	+26	−19	+ 61	− 61	−18
Sum	+ 37	+ 7	− 43	+26	+27	+13	−149	−17	+178	+25	+ 8	+120	−128	−82
						Sum $\nu=0$, 1, 2, 3, 4, and 5								
....	......	......	......	......	.....	−94	+ 64	+54	+ 41	+65	......	......	......	......

from $2\nu=-24°.4$ to $2\nu=0°$, and from $2\nu=65°.6$ to $2\nu=90°$, which are found to be

$$a(M_2)=-14.3\gamma \quad b(M_2)=-9.7\gamma \tag{31.6}$$

With these values our normal equations become

$$54.7\, a(N_2)+1.0\, b(N_2) = -372\gamma-(-4.8)(-14.3\gamma)-(+5.4)(-9.7\gamma) = -389\gamma \tag{31.7}$$

$$1.0\, a(N_2)+59.3\, b(N_2) = +54\gamma-(0.0)(-14.3\gamma)-(2.1)(-9.7\gamma) = +34\gamma \tag{31.8}$$

Neglecting first the "mixed" term (with factor 1.0 here), we get the approximations $a(N_2) = -(389/54.7) = -7.1\gamma$, $b(N_2) = +(34/59.3) = +0.6\gamma$; inserting these in the "mixed" terms we obtain

$$a(N_2) = -7.12\gamma \quad b(N_2) = +0.69\gamma \tag{31.9}$$

We are now prepared to find $L(N_2)$ relative to $L(M_2)$ in the material considered as in § 29. In amplitude and phase, (31.6) and (31.9) give, if we multiply $a(N_2)$ and $b(N_2)$ by the factor $(\pi/8)/\sin(\pi/8) = [1+(1/40)]$ in order to correct for the smoothing over 45° in $(s-p)$

$$L(M_2) \equiv 17.3\gamma \times \sin(2\nu+236°) \tag{31.10}$$

$$L(N_2) \equiv 7.3\gamma \times \sin[2\nu+(s-p)+276°] \tag{31.11}$$

Expressed with lunar time τ' instead of ν (see 29.4 and 29.5), the amplitudes are the same, but the phases must be reversed [and changed by a constant which is the same for $L(M_2)$ and $L(N_2)$ and therefore irrelevant here]; therefore, in $2\tau'$, amplitudes and phases are for $L(M_2)$ and (at perigee, $s=p$) for $L(N_2)$

$$L(M_2) \equiv (17.3\gamma, 90°) \quad L(N_2) \equiv (7.3\gamma, 50°) \tag{31.12}$$

or, expressed as in (29.5) relative to $L(M_2) \equiv (100, 90°)$, we obtain, in amplitude and phase, $L(N_2) = (42, 50°)$. Finally, expressed as rectangular harmonic coefficients, that is, factors of $\cos 2\tau'$ and $\sin 2\tau'$—in other words, in a harmonic dial of frequency $2\tau'$—upward and toward the right

$$L(M_2) \equiv (+100, 0) \quad L(N_2) = (+32, +27) \tag{31.13}$$

For the combination of the four results for the four three-hour intervals per day, it is better not to use the individual results (31.13), but to retain the original amplitude in order to give the appropriate weight to those intervals of the day in which $L(M_2)$ is large. We write then (31.12) in rectangular coordinates and obtain

$$\left.\begin{array}{l} 05^h\text{-}06^h \text{ to } 08^h\text{-}09^h,\ L(M_2) = (+4.8\gamma,\ 0.0\gamma);\ \ L(N_2) = (+3.0\gamma,\ +1.1\gamma) \\ 08^h\text{-}09^h \text{ to } 11^h\text{-}12^h,\ L(M_2) = (+16.1\gamma,\ 0.0\gamma);\ L(N_2) = (+1.7\gamma,\ -3.1\gamma) \\ 11^h\text{-}12^h \text{ to } 14^h\text{-}15^h,\ L(M_2) = (+17.3\gamma,\ 0.0\gamma);\ L(N_2) = (+5.6\gamma,\ +4.7\gamma) \\ 14^h\text{-}15^h \text{ to } 17^h\text{-}18^h,\ L(M_2) = (+8.6\gamma,\ 0.0\gamma)\ ;\ L(N_2) = (+2.9\gamma,\ -4.1\gamma) \end{array}\right\} \tag{31.14}$$

The sums of the sine-wave vectors are

$$\Sigma L(M_2) = (46.8\gamma,\ 0.0\gamma) \qquad \Sigma L(N_2) = (13.2\gamma,\ -1.4\gamma)$$

or, on reduction to $L(M_2) = (100, 0) \equiv (100, 90°)$, $L(N_2)$ becomes, in per cent

$$(+28.2, -3.0) \equiv (28.3, 96°) \tag{31.15}$$

This is the final result on the distance-effect for January Min_1, to be represented in the harmonic dial as in § 30, and to be combined with the results for other groups of months.

$L(L_2)$ and $L(2N)$ may be formed in a similar manner.

§ 32. *A new formula for* $L(M_2)$

The lunar semimonthly sine-waves in the daily ranges A are a combination of such waves appearing in the hourly means for each fixed hourly interval which will next be considered. For instance, in the average for the months December, January, February, 1922-39, the hourly means of H for the interval 11^h to 12^h, standard time, are found to contain the lunar semimonthly wave $30.5\gamma \sin(2\nu+341°)$. These lunar semimonthly waves for each interval according to mean solar time, t, have been expressed in the harmonic dial (Fig. 15-A) as

$$c(t)\sin[2\nu+\alpha(t)]$$

The function $c(t)$ is the solar daily variation of the amplitude of the lunar semimonthly wave at the solar hour t; it is expressed in Figure 15-A

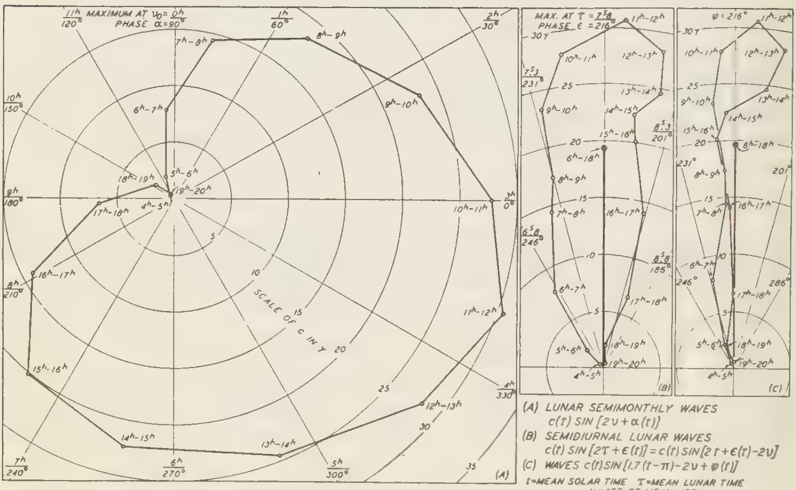


FIG. 15—THREE HARMONIC DIALS EXPRESSING LUNAR GEOMAGNETIC TIDES IN HORIZONTAL INTENSITY AT HUANCAYO, DECEMBER, JANUARY, AND FEBRUARY, 1922–39

by the radius from the origin and in Figure 16 by the dots (for the observed values) and a smooth curve. $c(t)$ can be assumed to express the current-density of the ionospheric current; assuming S. Chapman's estimate that 0.6 ΔH is the contribution of the primary exterior ionospheric currents to the horizontal field change ΔH, an increase of H by one γ is produced by an ionospheric current from west to east of surface-density one amp/km, or about 1100 amperes across 10° of latitude.

Two features dominate the function $c(t)$: The contrast between day and night, and the symmetry in the morning rise and the evening decrease. There is an asymmetry around noon; from 11^h to 14^h the observed function $c(t)$ looks as if it is shifted about half an hour earlier according to symmetry with respect to noon. But, on the whole, the ob-

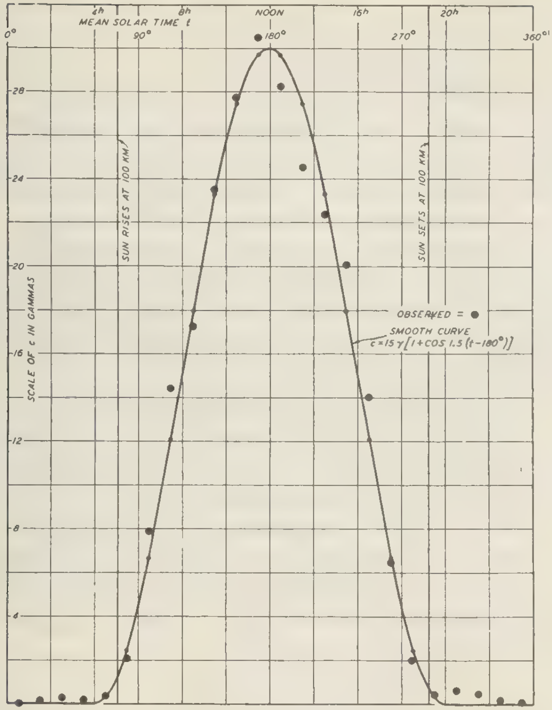


FIG. 16—DAILY VARIATION OF LUNAR SEMIMONTHLY AMPLITUDE c, HORIZONTAL FORCE, HUANCAYO, DECEMBER, JANUARY, AND FEBRUARY 1922-39

served function is quite satisfactorily approximated by a zero-line in the eight night hours centered at midnight, and a sine-curve of 16-hour period, with its maximum at noon. Reckoning solar time as usual from 0° to 360° starting at midnight, the curve from 04^h to 20^h is

$$c(t)=15\gamma[1+\cos 1.5(t-180°)]$$

drawn in Figure 16.

According to § 2, (4*a*), Part I, the parameter ν characterizing a day is related to the lunar and solar times τ and t as follows

$$\nu=t-\tau-0.339(t-104°.7) \tag{32.1}$$

so that

$$\sin[2\nu+\alpha(t)]=\sin[2\tau+\epsilon(t)] \tag{32.2}$$

with

$$\epsilon(t)=180°-2t+0.068(t-104°.7)-\alpha(t) \tag{32.3}$$

The constants $[\alpha(t)+\epsilon(t)]=[180°-2t+0.068(t-104°.7)]$ are given for the 24 hourly intervals in Table 17.

Table 17—*Values of* $[\alpha(t)+\epsilon(t)]$ *for the 24 hourly intervals of one day*

00^h-01^h	01^h-02^h	02^h-03^h	03^h-04^h	04^h-05^h	05^h-06^h
159°.0	130°.0	101°.0	72°.0	43°.1	14°.1
06^h-07^h	07^h-08^h	08^h-09^h	09^h-10^h	10^h-11^h	11^h-12^h
345°.1	316°.1	287°.1	258°.1	229°.2	200°.2
12^h-13^h	13^h-14^h	14^h-15^h	15^h-16^h	16^h-17^h	17^h-18^h
171°.2	142°.2	113°.2	84°.3	53°.3	26°.3
18^h-19^h	19^h-20^h	20^h-21^h	21^h-22^h	22^h-23^h	23^h-24^h
357°.3	328°.3	274°.9	245°.9	216°.9	188°.0

This makes it possible to transform lunar semimonthly waves into equivalent semidiurnal waves. These waves are represented in Figure 15-*B*; this harmonic dial is turned so that the vector representing the average lunar semidiurnal wave for the daytime 06^h to 18^h points upward; the phase of this average wave is actually $\epsilon=216°$ according to a maximum for $\tau=117°$ or $7^h.8$ mean lunar time.

Figure 15-*B* shows clearly that maxima (and minima) of the lunar semidiurnal waves occur, with respect to the Moon, about an hour earlier in the morning than in the afternoon. In other words, on each individual day, the time between a morning maximum and the following afternoon minimum of the lunar semidiurnal wave is not six but about seven lunar hours. The lunar wave-variation in daytime has therefore the appearance of a sine-wave with a period longer than half a lunar day; but from day to day its phase-angle at noon shifts regularly with mean lunar time, as if the wave overnight catches up with lunar time. Instead of the lunar semidiurnal wave of variable amplitude $c(t)$ and phase-angle $\epsilon(t)$ written in solar time t

$$c(t)\sin[2\tau+\epsilon(t)]=c(t)\sin[2t+\epsilon(t)-2\nu] \qquad (32.4)$$

the lunar variation is therefore better expressed by a wave of frequency 1.7 per solar day, or period $(24/1.7)=14$ hours

$$c(t)\sin[1.7(t-180°)-2\nu+\phi(t)] \qquad (32.5)$$

better in the sense that the phase-angle $\phi(t)$ is more nearly constant throughout the day than $\epsilon(t)$.

Figure 15-*C* expresses this fact. Inserting the expression for $c(t)$ and the average value $\phi=216°$, we obtain

$$15\gamma[1+\cos 1.5(t-180°)]\sin[1.7(t-180°)-2\nu+216°] \qquad (32.6)$$

as the general formula which expresses the observed average geomagnetic tidal effect of the mean Moon on H at Huancayo from 04^h to 20^h in the average for the months December, January, and February, 1922-39, by four parameters, namely, an amplitude (15γ), two frequencies (1.5 and 1.7) and a phase-angle (216°). The influence of the sunspot-cycle is practically restricted to an increase of the amplitude with the number of sunspots.

§ 33. *Discussion and interpretation of the new formula*

This expression needs less parameters and seems therefore more adequate than the ordinary harmonic analysis which expresses the lunar

variation by eight parameters, namely, the amplitudes and phase-angles of four superposed sine-waves (with constant amplitudes) of frequencies 1, 2, 3, and 4 per solar day and phase-angles decreasing like (-2ν), according to Chapman's phase-law. The new expression has been developed in a series of such ordinary sine-waves with constant amplitudes and the phase-law terms are found to be indeed the most important ones.

From the standpoint of the dynamo-theory the new expression is easily interpreted, thus, in turn, strengthening confidence in that theory. Consider the current-circuits in the Southern Hemisphere which in December to February cause the lunar wave L in H at Huancayo. If hourly values were rearranged in rows corresponding to lunar days, the average row for the lunar month would be a regular semidiurnal wave of constant amplitude corresponding to four ionospheric current-circuits equally intense and equally spaced around the Southern Hemisphere, each covering an octant of a fictitious homogeneous ionosphere in which the solar daily variations of ion-content have been averaged. On each particular day only the current-circuits on the daylight side are active and the highest conductivity is confined to the eight hours from 08^h to 16^h. The current-circuits in that part of the ionosphere will therefore "expand" from the noon meridian toward the meridians of sunrise and sunset, feeding, so to say, on those circuits which are partially or wholly suppressed on the night side.

These results will be put on a firmer basis by the new calculations given in § 24. It seems that the asymmetry with respect to noon, with higher lunar semimonthly waves in the forenoon, is real, and that it might be interpreted by a decrease in the intensity of the ionospheric L-current-system while, during its passage around the world, it passes Huancayo. In other words, the current-system reaches its highest intensity *before* its foci pass the meridian of Huancayo.

The current-intensities in the ionosphere are highest near noon and do not show any conspicuous lag behind the daily change in the Sun's altitude. This feature agrees with directly observed changes in ion-density in the low ionosphere (E-region). The seat of the main lunar currents must therefore also be low in the ionosphere, in regions in which the recombination is fast, so that ion-production and ion-attachment are in approximate equilibrium, certainly not as high as the F-region which shows an appreciable lag.

§ 34. *Relation of our method to that of Chapman and Miller*

The main difference between the method described here and that of Chapman and Miller [3] is that we use the fixed-hour method and semimonthly waves, while they start with the fixed-age method and the harmonic analysis of daily variations. The handicap of the fixed-hour method, described in Part I in § 10, has since been overcome in Part II by the use of the day-to-day changes (§ 20) and the adoption of a zero night level. It appears to us that the fixed-hour method, in this new form, is definitely superior, not only with regard to elimination of irregularities, but even as a description of the final results, because the solar daily variation of the lunar effect becomes clearer (§ 32).

Chapman and Miller use *group-sums* instead of *group-averages* in

the harmonic analysis, and they fit their sine-waves by preservation-factors, which is identical with the prescription of the method of least squares leading to normal equations (§ 31). Use of the group-sums, with different number of days in each group, makes the calculations more cumbersome through mixed terms; harmonic analysis of group-averages is more elegant, because the usual formulas can be used. But the use of the sums for the computation of $L(N_2)$ is imposed by the quite unequal number of days [$n_N(\nu, s-p)$ in § 31], especially the occasional occurrence of empty groups ($n=0$); therefore in § 31, we have adopted the practice of Chapman and Miller.

However, in § 24, for $L(M_2)$, we have used the convenient averages and not the sums. The numbers of days in the six ν-groups are 22, 20, 16, 14, 17, 25, well removed from zero. Of course, with regard to the error in the result, the wilful assignment of *equal* weight to these groups and to their averages *increases* the standard deviation. But it can be easily shown, by the usual formulas for the propagation of errors, that the elaborate use of the sums instead of the averages, for numbers of days as unequal as the six numbers above, would produce a standard deviation in the weighted result which is only a few per cent smaller than that in the result obtained from the averages. Once this had been recognized, it was clear that it was both safe and economical to use averages and not sums for computing $L(M_2)$.

In § 31, the elimination of residuals due to $L(M_2)$ from the equations for $L(N_2)$ appeared quite necessary, judging by the magnitude of the terms with $a(M_2)$ and $b(M_2)$ on the right-hand side. But in computing $L(M_2)$, the residuals due to $L(N_2)$ are negligible, because the relative magnitude of these residuals is reduced as the square of the ratio of $L(N_2)$ to $L(M_2)$, about one-tenth.

Acknowledgments—In the analysis of the hourly values in horizontal intensity from Huancayo for the years 1922-39, we acknowledge with thanks valuable computing assistance from W. E. Scott and Miss E. Balsam and the assistance of W. C. Hendrix in the preparation of the Figures.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

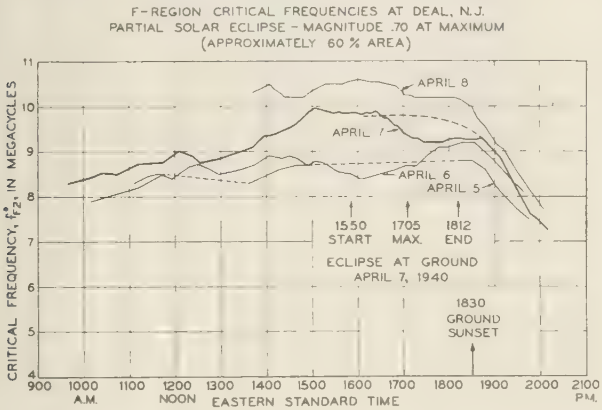
LETTERS TO EDITOR

(See also page 424)

F-REGION CRITICAL FREQUENCIES AT DEAL, NEW JERSEY, DURING PARTIAL SOLAR ECLIPSE OF APRIL 7, 1940

F-region critical frequencies were obtained at Deal, New Jersey (latitude 40° 01′ north, longitude 75° 15′ west), on the day of the solar eclipse of April 7, 1940. The eclipse was partial in the vicinity of Deal with a magnitude of approximately 0.70 (60 per cent area).

The results obtained are given in Figure 1 which shows the variation in *F*-region critical frequency throughout the day of the eclipse as well as similar curves for the two days preceding and one day following. The solid-line curve for the day of the eclipse shows the actual variations measured, while the dashed line for the same day indicates the possible trend in the absence of eclipse.



The effect of the eclipse on the ionization of the F_2-region is not pronounced and no conclusions are to be drawn from these data. We are presenting them as a matter of record.

The data were obtained by G. M. Eberhardt, W. M. Goodall, and the writer.

J. P. Schafer

Bell Telephone Laboratories, Inc.,
Deal, New Jersey, August 21, 1940

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, JULY TO SEPTEMBER, 1940

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The three columns for each month in Table 1 give (1) the mag-

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 409-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937), 43, 83-87, 174-178, 328-331, 491-494 (1938); **44**, 94-99, 215-219, 349-352, 487-491 (1939); **45**, 99-104, 214-218, 373-377 (1940).

Table 1—*Summary American URSI daily broadcasts of cosmic data, July to September, 1940*

Greenwich date	July Magnetism: Character	July Magnetism: Type	July Magnetism: GMT beginning disturbance		August Magnetism: Character	August Magnetism: Type	August Magnetism: GMT beginning disturbance		September Magnetism: Character	September Magnetism: Type	September Magnetism: GMT beginning disturbance	
1	0	...	..	..	0	...	..	..	1	*i*	..	..
2	0	...	..	..	0	...	..	..	0	...	..	..
3	1	*i*	18	25	1	*i*	05	00	0	...	..	..
4	1	*i*	..	..	0	...	..	..	0	...	..	..
5	1	*i*	..	..	0	...	..	..	0	*b*	03	25
6	1	*i*	..	..	0	...	..	..	0	...	..	..
7	0	...	..	..	0	...	..	..	1	*i*	00	45
8	0	...	..	..	0	...	..	..	0	...	..	..
9	1	*i*	..	..	1	*i*	05	00	0	...	..	..
10	1	*i*	..	..	0	...	..	..	0	...	..	..
11	0	...	..	..	0	...	..	..	0	...	..	..
12	0	...	..	..	0	...	..	..	0	...	..	..
13	1	*i*	08	00	0	...	..	..	0	...	..	..
14	1	*i*	..	..	0	...	..	..	1	*i*	18	10
15	1	*i*	..	..	0	...	..	..	0	...	..	..
16	0	...	..	..	0	...	..	..	0	...	..	..
17	0	...	..	..	0	...	..	..	0	...	..	..
18	0	...	..	..	0	...	..	..	0	*b*	16	00
19	0	...	..	..	0	...	..	..	0	...	..	..
20	0	...	..	..	0	...	..	..	0	...	..	..
21	0	...	..	..	0	...	..	..	0	...	..	..
22	1	*i*	..	..	0	...	..	..	0	...	..	..
23	0	...	..	..	0	...	..	..	0	...	..	..
24	0	...	..	..	0	...	..	..	0	...	..	..
25	0	...	..	..	0	...	..	..	0	...	..	..
26	0	...	..	..	1	*i*	10	00	1	*i*	17	03
27	0	...	..	..	1	*i*	..	..	1	*i*	..	..
28	0	...	..	..	0	...	..	..	1	*i*	..	..
29	0	...	..	..	0	...	..	..	0	...	..	..
30	1	*i*	..	..	0	...	..	..	0	...	..	..
31	1	*i*	..	..	1	*i*	16	05				
Mean	0.4	...	..	..	0.2	...	..	..	0.2	...	..	..

Greenwich mean time for ending of storms: 24h, July 6; 06h, July 15; 19h August 3; 24h, August 9; 11h, August 27; 21h, September 1; 13h, September 7; 24h, September 14; 21h 15m, September 18; 24h, September 28.

netic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table.

Beginning with October 27, 1938, Mount Wilson discontinued supplying sunspot-numbers, since interested investigators have available the sunspot-counts from Tokyo published regularly in the weekly Science

TABLE 2—*Kennelly-Heaviside Layer heights, Washington, D. C., July to September, 1940*
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1940	*kc/sec*	*km*	1940	*kc/sec*	*km*	1940	*kc/sec*	*km*	1940	*kc/sec*	*km*
July 3	2,500	130	July 17	6,500	490	Aug. 14	7,000	500	Sep. 4	8,600	460
" "	3,000	130	" "	6,700	700	" "	7,200	640	" "	8,700	600
" "	3,500	130	" "	6,750	*	" "	7,300	*	" "	8,800	*
" "	4,000	130	" 24	2,500	120	" 21	2,500	120	" 11	2,500	120
" "	4,600	120	" "	3,500	120	" "	3,000	120	" "	3,100	120
" "	4,600	320	" "	4,500	120	" "	3,500	130	" "	3,400	130
" "	4,800	120	" "	4,300	230	" "	3,700	140	" "	3,600	260
" "	4,800	580	" "	4,500	280	" "	3,800	260	" "	3,900	210
" "	5,200	420	" "	4,600	380	" "	4,000	200	" "	4,500	250
" "	5,500	460	" "	4,700	600	" "	4,100	200	" "	5,000	330
" "	5,700	110	" "	4,900	600	" "	4,200	210	" "	5,800	310
" "	5,700	560	" "	5,100	450	" "	4,400	230	" "	6,500	300
" "	5,800	110	" "	5,400	440	" "	4,700	290	" "	7,500	320
" "	6,200	470	" "	5,800	480	" "	5,000	390	" "	8,400	330
" "	6,500	540	" "	6,000	500	" "	5,200	360	" "	8,400	380
" "	6,600	110	" "	6,000	600	" "	5,500	330	" "	8,800	350
" "	6,600	700	" "	6,200	480	" "	5,700	320	" "	8,800	470
" "	6,650	110	" "	6,500	500	" "	6,200	320	" "	8,900	350
" "	8,000	110	" "	6,700	550	" "	6,500	330	" "	8,900	700
" "	9,200	110	" "	6,800	600	" "	7,000	350	" "	9,200	380
" 10	2,500	120	" "	6,900	*	" "	7,000	400	" "	9,500	430
" "	3,000	120	" 31	2,500	110	" "	7,500	360	" "	9,700	600
" "	3,600	120	" "	3,500	120	" "	7,500	570	" "	9,750	*
" "	3,800	130	" "	3,800	260	" "	8,000	420	" 18	2,500	120
" "	3,850	140	" "	4,100	200	" "	8,300	600	" "	3,600	120
" "	3,900	260	" "	4,200	200	" "	8,400	*	" "	3,700	*
" "	3,950	220	" "	4,400	320	" 28	2,500	110	" "	3,850	190
" "	4,000	210	" "	4,550	530	" "	3,000	120	" "	3,950	350
" "	4,100	210	" "	4,700	430	" "	3,700	130	" "	4,100	220
" "	4,200	220	" "	5,300	600	" "	4,000	220	" "	4,300	250
" "	4,400	250	" "	5,600	480	" "	4,200	220	" "	4,900	280
" "	4,600	300	" "	6,100	650	" "	4,500	250	" "	6,000	300
" "	4,800	360	" "	6,200	*	" "	4,800	320	" "	7,000	320
" "	4,900	700	Aug. 7	2,500	120	" "	5,100	380	" "	7,000	340
" "	5,000	680	" "	4,200	120	" "	5,500	370	" "	8,000	360
" "	5,100	580	" "	5,000	120	" "	6,000	380	" "	8,000	430
" "	5,200	610	" "	4,100	220	" "	6,500	390	" "	8,400	380
" "	5,250	720	" "	4,500	320	" "	6,500	430	" "	8,400	600
" "	5,500	300	" "	4,700	500	" "	6,900	400	" "	9,000	460
" "	5,600	320	" "	4,800	700	" "	6,900	660	" "	9,200	650
" "	5,800	720	" "	5,100	450	" "	7,500	470	" "	9,250	*
" "	6,000	*	" "	5,300	340	" "	7,700	700	" 25	2,500	120
" 17	2,500	120	" "	5,300	460	" "	7,800	*	" "	3,300	130
" "	3,000	120	" "	5,400	440	Sep. 4	2,500	120	" "	3,450	200
" "	3,500	130	" "	5,400	500	" "	3,000	120	" "	3,600	130
" "	3,850	260	" "	5,500	700	" "	3,700	120	" "	3,900	120
" "	4,000	180	" "	5,800	490	" "	3,700	300	" "	3,900	210
" "	4,200	190	" "	6,200	570	" "	3,800	200	" "	4,500	270
" "	4,300	220	" "	6,300	700	" "	3,900	190	" "	4,900	310
" "	4,450	290	" "	6,350	*	" "	4,000	220	" "	5,300	270
" "	4,600	290	" 14	2,500	120	" "	4,200	230	" "	5,300	320
" "	4,800	400	" "	3,500	120	" "	4,900	300	" "	6,000	320
" "	4,850	550	" "	3,800	120	" "	5,200	250	" "	6,800	310
" "	5,000	460	" "	3,900	360	" "	5,200	340	" "	7,800	330
" "	5,300	300	" "	4,000	210	" "	5,700	300	" "	7,800	360
" "	5,300	420	" "	4,100	210	" "	5,700	330	" "	8,500	350
" "	5,500	360	" "	4,200	230	" "	6,200	330	" "	8,500	400
" "	5,500	430	" "	4,600	350	" "	7,000	350	" "	9,200	380
" "	5,600	450	" "	4,900	460	" "	7,600	350	" "	9,200	480
" "	5,600	500	" "	5,100	400	" "	7,600	420	" "	9,500	400
" "	5,850	470	" "	5,500	400	" "	7,800	360	" "	9,500	800
" "	5,850	600	" "	6,000	410	" "	7,800	520	" "	9,800	430
" "	5,900	470	" "	6,000	430	" "	7,900	360	" "	10,000	550
" "	5,900	750	" "	6,500	430	" "	7,900	700	" "	10,200	650
" "	6,200	460	" "	6,500	650	" "	8,300	390	" "	10,300	*

* = No value obtained.

TABLE 3—*American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for July to September, 1940*

Day	July			August			September		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	0.4	0.1	0.2	0.4	0.1	0.2	0.9	0.6	0.8
2	0.0	0.0	0.0	0.0	0.6	0.3	0.4	0.6	0.5
3	0.1	0.6	0.4	0.8	1.0	0.9	0.7	0.7	0.7
4	0.9	0.6	0.7	0.3	0.0	0.1	0.4	0.5	0.5
5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.4
6	0.4	0.4	0.4	0.6	0.5	0.5	0.1	0.3	0.2
7	0.0	0.0	0.0	0.4	0.4	0.4	0.9	0.5	0.7
8	0.0	0.3	0.1	0.5	0.1	0.3	0.5	0.4	0.5
9	0.6	0.5	0.5	0.8	1.1	1.0	0.5	0.4	0.4
10	0.9	0.7	0.8	0.4	0.5	0.4	0.1	0.0	0.0
11	0.5	0.1	0.3	0.6	0.7	0.6	0.0	0.0	0.0
12	0.1	0.0	0.0	0.4	0.1	0.2	0.0	0.0	0.0
13	0.7	1.4	1.1	0.0	0.0	0.0	0.0	0.2	0.1
14	0.7	0.6	0.7	0.5	0.0	0.2	0.2	1.0	0.6
15	0.4	0.5	0.5	0.0	0.0	0.0	0.4	0.5	0.5
16	0.1	0.0	0.1	0.0	0.0	0.0	0.4	0.6	0.5
17	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.1	0.8	0.4	0.0	0.1	0.1
19	0.0	0.0	0.0	0.1	0.6	0.4	0.0	0.0	0.0
20	0.0	0.1	0.0	0.6	0.2	0.4	0.2	0.6	0.4
21	0.2	0.4	0.3	0.0	0.1	0.1	0.6	0.4	0.5
22	0.7	0.5	0.6	0.2	0.4	0.3	0.2	0.4	0.3
23	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0
24	0.6	0.3	0.4	0.0	0.0	0.0	0.1	0.0	0.0
25	0.5	0.0	0.2	0.0	0.2	0.1	0.6	0.8	0.7
26	0.1	0.0	0.0	0.4	0.9	0.6	0.1	1.6	0.8
27	0.0	0.0	0.0	0.9	0.5	0.7	0.9	0.8	0.9
28	0.1	0.0	0.1	0.5	0.4	0.5	0.1	0.8	1.0
29	0.3	0.4	0.4	0.4	0.3	0.3	0.4	0.2	0.3
30	0.6	0.8	0.7	0.1	0.1	0.1	0.0	0.4	0.2
31	0.7	0.5	0.6	0.0	0.3	0.1			
Means	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4

Service Research Aid Announcements and the monthly tabulation of Wolf numbers, promptly prepared at Zürich, which appear monthly in the Monthly Weather Review and quarterly in this JOURNAL.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937, the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March, 6, 1937, solar-constant values were discontinued owing to an important change in methods.

The data for Table 2 of Kennelly-Heaviside Layer heights which are self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and its values for the first twelve, second twelve, and twenty-four hours of each Greenwich day for July to September, 1940, are given in Table 3.

H. F. JOHNSTON

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION WASHINGTON,
Washington, D. C., October 15, 1940

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS AT WASHINGTON, D. C., JULY TO SEPTEMBER, 1940[1]

The following ionosphere data are in continuation of those published in each issue of this JOURNAL[2]. These data are now all obtained by automatic recording.

The data given in Table 1 are in part somewhat different from those presented graphically each month in *Proceedings of the Institute of Radio Engineers*, because the averages given there are for undisturbed days while these are for all days of the month.

Included is also Table 2 giving daily values of the critical frequencies of the E-, F_1-, and F_2-layers at noon, and the F-layer at midnight.

The data on critical frequencies also give implicitly the maximum ionization-densities of the ionosphere layers. The equivalent electron-density in electrons per cubic centimeter is 0.0124 times the square of the critical frequency in kilocycles per second.

Key to symbols:

EST = Eastern Standard Time (75° west meridian time)
* = less than ten measurements
† = day considered disturbed by ionosphere storm

[1]Report prepared by S. S. Kirby, N. Smith, A. S. Taylor, and F. R. Gracely.
[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*
(Average for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*
			July, 1940						*August, 1940*						*September, 1940*			
00			304			5.14			307			4.76			309			5.03
01			303			4.80			308			4.54			310			4.71
02			306			4.32			307			4.17			312			4.40
03			301			4.03			315			3.84			308			4.11
04			302			3.66			320			3.46			313			3.90
05			295	1.70		3.75			313	1.22*		3.34			311			3.58
06		230*	247	2.31	3.60*	4.56	120*	257*	254	2.11	3.50*	4.51			263	1.84		4.69
07	127*	232	342	2.80	4.16	5.04	120	227	296	2.66	3.96	5.32			243	2.53		6.42
08	120	216	354	3.14	4.43	5.66	122	227	323	3.05	4.39	5.89	121*	224	271	2.94	4.30	7.35
09	119	223	368	3.39	4.56	5.96	120	218	359	3.37	4.62	6.21	123	216	274	3.24	4.59	8.19
10	120*	211	381	3.60	4.72	6.11	118	210	370	3.58	4.74	6.30	120	213	290	3.44	4.73	8.44
11	120	209	380	3.71	4.81	6.11	117	208	382	3.74	4.87	6.40	120	210	298	3.58	4.86	8.71
12	120	211	404	3.80	4.84	6.23	117	211	418	3.82	4.88	6.50	121	210	303	3.61	4.91	9.09
13	119*	223	392	3.76	4.81	6.26	118	219	403	3.80	4.86	6.71	123	215	304	3.57	4.89	9.31
14	118*	218	384	3.66	4.75	6.22	118	221	374	3.68	4.78	6.78	123	222	300	3.44	4.77	9.47
15	120*	227	352	3.51	4.70	6.50	120	223	380	3.48	4.69	6.74	126	228	287	3.25	4.69	9.46
16	119	232	343	3.29	4.54	6.65	122	224	346	3.25	4.53	6.90	124	232	271	2.97	4.08	9.39
17	122	237	322	2.96	4.24	6.87	124	235	310	2.90	4.13	6.88		240*	249	2.56	3.82*	9.28
18		240*	284	2.53	3.84	7.10		252*	278	2.36	3.60*	7.09			240	1.80		9.00
19			257	2.01		7.29			258	1.68*		7.12			244			8.11
20			255			7.10			264			6.86			256			7.00
21			268			6.48			278			6.14			280			5.97
22			281			5.92			287			5.49			307			5.47
23			290			5.48			298			5.02			311			5.22

LE 2—*Midnight and noon critical frequencies for each day, National Bureau of Standards, Washington, D. C.*

y	00 EST	12 EST			00 EST	12 EST			00 EST	12 EST		
	f^o_F	$f^o_{F_2}$	$f^o_{F_1}$	f^o_E	f^o_F	$f^o_{F_2}$	$f^o_{F_1}$	f^o_E	f^o_F	$f^o_{F_2}$	$f^o_{F_1}$	f^o_E
	mc/sec	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
	July, 1940				*August, 1940*				*September, 1940*			
1	5.8	...	...	...	5.0	6.7	5.0	3.8	†7.0	†8.1	†5.1	†3.8
2	...	...	...	...	4.5	6.8	5.0	3.8	†4.0	8.9	5.0	3.8
3	5.6	†5.8	†4.8	†...	4.9	†5.2	†4.6	†3.7	†6.0	†8.6	†4.8	†3.8
4	†6.4	†5.9	†5.0	†...	†4.4	†5.2	†4.7	†3.7	†5.3	7.9	5.1	3.7
5	†...	...	...	...	5.0	6.3	5.0	3.8	†5.5	7.0	5.1	3.7
6	5.0	6.2	4.9	...	4.6	†5.1	†4.8	†3.7	5.0	9.2	...	3.7
7	5.3	6.4	4.8	...	†3.7	†5.5	†4.8	†3.7	†5.7	†...	†...	†...
8	5.3	7.2	4.9	...	5.0	5.5	4.7	3.8	†4.5	...	...	...
9	6.1	6.0	...	...	4.5	†<4.5	†4.5	†3.7	5.1	9.3	...	3.6
0	†5.6	†5.2	†4.9	†3.9	†3.0	†4.8	†4.7	†3.7	4.9	8.5	4.9	3.7
1	†4.5	†...	†...	†3.9	4.7	5.6	4.8	3.6	5.2	8.9	5.0	3.6
2	†...	†...	†...	†...	4.8	†5.3	†4.7	†3.8	5.0	7.9	4.8	3.6
3	†...	†...	†...	†...	†4.1	†5.2	†4.8	†3.8	4.8	8.4	4.9	3.6
4	†...	†...	†...	†...	†5.0	6.5	4.9	3.8	5.0	8.3	4.9	3.5
5	†...	†6.1	†4.9	†3.8	5.1	7.0	4.9	4.0	5.5	9.7	4.8	3.5
6	...	...	...	...	5.4	6.9	4.9	3.9	4.6	10.1	4.8	3.6
7	5.6	5.9	4.8	3.8	5.4	7.2	4.9	3.9	3.8	8.3	...	...
8	4.9	7.3	...	3.8	5.1	7.6	5.1	3.9	4.8	8.6	4.8	3.6
9	5.4	6.3	5.0	3.8	4.8	7.9	5.1	3.9	5.1	8.5	...	...
0	5.0	6.8	4.9	3.8	5.3	7.6	4.8	3.9	5.5	9.9	..	3.6
1	5.1	6.1	4.9	3.9	4.9	7.5	5.0	3.8	5.3	9.0	4.8	3.6
2	†4.2	†5.5	†4.7	†3.7	4.3	†5.5	†4.7	†3.8	5.2	9.7	4.8	3.6
3	†4.1	6.2	4.9	3.8	4.5	6.5	5.0	3.9	†5.2	10.2	5.1	3.7
4	5.2	6.0	4.9	...	5.0	7.7	4.9	3.9	†5.0	9.5	...	3.6
5	5.3	5.6	4.7	3.8	5.3	7.6	4.8	3.9	†6.1	9.5	4.9	3.5
6	5.1	5.9	4.8	...	5.6	7.1	5.0	3.9	4.5	9.8	4.9	3.5
7	4.7	7.5	4.8	3.8	†4.1	†5.4	†4.7	†3.7	†3.0	10.5	4.8	3.5
8	5.0	7.0	4.8	3.8	†4.2	6.9	5.1	3.9	†4.8	11.0	5.0	3.4
9	5.2	†6.9	†4.9	†3.8	4.9	8.3	5.2	3.9	†4.6	9.7	4.9	3.5
0	†4.1	†5.9	†4.8	†3.8	4.8	8.7	5.3	3.9	†4.2	†9.4	†4.8	†3.5
1	†4.9	†5.4	†4.6	†3.7	5.7	8.0	5.1	3.8				

† = Ionosphere-storm day.

National Bureau of Standards,
United States Department of Commerce,
Washington, D. C.

SOLAR AND MAGNETIC DATA, JULY TO SEPTEMBER, 1940, MOUNT WILSON OBSERVATORY

Many sunspots were observed in July, August, and September, nine of them large enough to be visible without a telescope. Nevertheless, the Earth's magnetic field showed little disturbance.

Magnetic storms

Greenwich mean time						Range hor. int.
Beginning			Ending			
1940	*h*	*m*	*d*	*h*	*m*	γ
July 13	7	58*	14	18	.	150
Sept. 26	17	03*	28	13		165

*Sudden commencement.

Solar and magnetic data

July 1940

Day	K_2 Whole disk	K_2 Central zone	$H\alpha$ bright	$H\alpha$ dark	No. groups	Mag'c char.
1	3	3	4	3	8	0
2	3	3	4	3	6	0
3	4	3	4	3	8	0.5
4	4	3	4	2	8	0.5
5	4	3	4	2	9	0.5
6	3	3	4	2	7	0.5
7	3	3	4	3	7[b]	0
8	3	4	4	2	8[a]	0
9	3	4	4[c, d]	2	10[g]	0.5
10	4	4	4	2	8	1
11	3	3	4	2	8[h]	0.5
12	4	3	..	..	9	0
13	3	2	4	3	8	1
14	3	3	3	3	6	1
15	3	3	4[d]	3	7	0.5
16	3	3	3	2	7[e]	0
17	3	3	3	3	6	0
18	3	2	3	2	5	0
19	3	1	..	..	8	0
20	3	2	3	2	9	0
21	3	3	3	2	9	0
22	3	3	3	3	9[a]	0.5
23	3	3	3	3	7	0
24	3	3	3	3	4	0
25	3	3	3	3	4	0.5
26	3	3	3	3	5	0
27	3	3	3[d]	3	5	0
28	3	3	3	3	4	0
29	..	..	3	3	4	0
30	3	3	3	3	5	0.5
31	3	3	3	3	5	0.5
Mean	3.2	2.9	3.4	2.6	6.9	0.3

August 1940

Day	K_2 Whole disk	K_2 Central zone	$H\alpha$ bright	$H\alpha$ dark	No. groups	Mag'c char.
1	4	3	4	3	5	0
2	3	3	3	2	5	0.5
3	3	4	3	2	10	1
4	4	3	3	2	12[g]	0
5	4	3	4[d]	2	10	0.5
6	3	2	3	2	11[b]	0.5
7	4	3	3	2	7	0
8	3	3	4	3	7	0
9	4	4	..	..	8[h]	1
10	3	4	4	3	9	0
11	3	3	3	3	8[h]	0.5
12	4	3	4[d]	3	8[e]	0.5
13	4	3	3[d]	3	9	0
14	4	2	4	3	8	0
15	4	2	3[d]	3	8	0
16	3	3	3	2	9[b, h]	0
17	3	3	..	..	10	0
18	3	3	3[d]	3	8	0.5
19	3	3	3	4	7	0
20	4	3	4	3	12[b, e]	0
21	4	3	4	3	13	0
22	4	3	4	3	13	0
23	4	3	4[d]	3	10	0
24	3	3	5	2	9	0
25	4	4	4	2	11	0
26	4	4	4	2	13	0.5
27	4	4	4	2	9	0.5
28	4	3	4	2	9	0
29	3	2	4	2	10	0
30	3	3	4	2	9	0
31	3	4	4	3	8	0
Mean	3.5	3.1	3.7	2.6	9.2	0.2

September 1940

Day	K_2 Whole disk	K_2 Central zone	$H\alpha$ bright	$H\alpha$ dark	No. groups	Mag'c char.
1	4	4	4[c]	2	8[g]	0.5
2	4	3	4	2	8	0.5
3	4	3	4	2	8	0.5
4	4	3	4	2	6	0.5
5	4	4	4	2	6	0
6	3	4	3	2	8	0
7	3	3	3	2	7	0.5
8	3	3	3	1	5	0
9	3	2	3	2	5	0.5
10	3	1	3	2	5	0
11	..	..	..	..	3	0
12	3	2	2	2	4[b]	0
13	2	2	3	3	4	0
14	3	3	3	3	5	0.5
15	3	3	2	2	4	0
16	3	3	3	3	6	0.5
17	3	3	3	3	6	0
18	3	3	3	3	7	0
19	3	2	3	3	5[h]	0
20	3	2	3	3	6	0
21	3	2	4	3	8	0.5
22	4	3	4	3	6	0
23	4	4	4	3	7	0
24	4	4	4	3	6	0
25	4	4	3	4	7	0.5
26	4	4	4	4	5	1.5
27	4	4	4	4	4[g]	1
28	3	3	3	4	4	0.5
29	3	3	3	4	5	0
30	3	3	3	4	5	0
31						
Mean	3.3	3.0	3.3	2.8	5.8	0.3

Note—For an explanation of these tables see this Journal, 35, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

[a, b] Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

[c, d] Very bright chromospheric eruptions; (*c*) less than 30° from the center of the disk, (*d*) more than 30° from the center of the disk.

[e, f, g, h, i, j, k, l] Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

When the magnetic storm of July 13 began, two large groups, Mount Wilson Nos. 6902 and 6905, were in longitude 78° west and 39° east, respectively.

When the storm of September 26 began, a large stable spot, No. 6991, was 12° east of the central meridian. It was a return of the preceding member of group No. 6965, which had been large and active when it crossed the solar disk from August 26 to September 6.

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY,
Pasadena, California

SETH B. NICHOLSON
ELIZABETH STERNBERG MULDERS

CORRECTION OF TWO ERRORS IN "TERRESTRIAL MAGNETISM AND ELECTRICITY"

(Volume 8 in series *Physics of the Earth*)

(I) On page 72, in Chapter II, *Magnetic instruments*, the following statement appears: "The Department of Terrestrial Magnetism of the Carnegie Institution of Washington designed an electromagnetic instrument in 1913 (Fig. 8); it was not built until 1920 and is described by Barnett [97]." This statement confuses two entirely different and independent designs, which resemble one another only in that both were designs of sine-galvanometers, all of which must have coils, tripods, etc. The first design was made by Dr. N. E. Dorsey, but the instrument was never constructed. The quite different instrument built in 1920 (C I W Sine-Galvanometer No. 1) was designed, and its construction supervised entirely by the writer, except that some small and unimportant details were left to the mechanician, and that, in order to save time and labor, an excellent tripod with its circle, and a telescope and scale, from old instruments in the laboratory, were placed at my disposal by Dr. J. A. Fleming.

In the article on the instrument [Reference 97] I stated that it had been designed at the request of Dr. L. A. Bauer, then Director of the Department. The additional statement should have been made that I had been interested in the design and construction of such an instrument ever since the work of W. Watson in 1901. I was thus naturally much pleased to learn from Dr. Bauer in 1918 that the opportunity of constructing such an instrument for the Department was at hand.

(II) On page 324, in Chapter VII, *On causes of the Earth's magnetism and its changes*, is the following statement: "The possibility that elementary magnets in a rotating body may align their axes with the axis of rotation in the manner of a gyrocompass was suggested by Maxwell." This is not correct. Maxwell, in his *Treatise* (1873), suggested the possible behavior of a gross permanent magnet, electromagnet, or electric coil as a gyrostat—a subject in which he had made experiments, with negative results, in or after 1861. But there is no evidence that Maxwell ever thought of applying the same idea to the countless elementary magnets within a neutral rod of magnetic substance, and thus to the phenomenon of magnetization by rotation. So far as I have been able to learn, this suggestion was first made by John Perry, in 1890.

THE UNIVERSITY OF CALIFORNIA,
THE CALIFORNIA INSTITUTE OF TECHNOLOGY,
Los Angeles and Pasadena, California, October 30, 1940

S. J. BARNETT

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

July to September, 1940

(*Latitude* 57° 03′.0 *N., longitude* 135° 20′.1 *or* 9^h 01^m.3 *W. of Gr.*)

July 13-14—A small disturbance began gradually at 09^h.5 GMT, July 13, with decreasing values of horizontal and vertical intensities. At 11^h 40^m the activity increased sharply and remained disturbed until about 14^h 30^m. Thereafter the values returned gradually to normal. The trace remained moderately disturbed until the close of July 14. Ranges: *D*, 114′; *H*, 1296 gammas; *Z*, 852 gammas.

August 2-3—A period of mild disturbance began at 18^h 50^m GMT, August 2, with a sudden commencement. Disturbed conditions prevailed until 19^h, August 3.

August 9—A small disturbance began gradually at about 09^h GMT, August 9, with sharply decreasing values of *H* and *Z*. After 14^h the conditions slowly returned to normal. The trace was quiet by 24^h. Ranges: *D*, 84′; *H*, 488 gammas; *Z*, 722 gammas.

September 14—A sudden commencement at 18^h 10^m GMT, September 14, was followed immediately by a large bay, with no accompanying disturbance.

September 26-28—A moderate storm began at 17^h 03^m GMT, September 26, with a sudden commencement having an increase of 6′ in east declination and then a decrease of 35′ during the first two minutes. There were similar, though smaller movements of the other traces. The storm did not progress beyond a moderate stage, with no large amplitude motions. After 12^h, September 28, the storm diminished to normal values. Ranges: *D*, 99′; *H*, 721 gammas; *Z*, 629 gammas.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory

July to September, 1940

(*Latitude* 38° 44′.0 *N., longitude* 76° 50′.5 *or* 5^h 07^m.4 *W. of Gr.*)

July 13-14—A storm began at 08^h 00^m GMT, July 13, and ended at 08^h, July 14. The elements were very active between 11^h 52^m and 15^h, July 13. Ranges: *D*, 26′; *H*, 215 gammas; *Z*, 50 gammas.

September 26-27—A mild storm began with a sudden commencement at 17^h 03^m GMT, July 26. Although the following two days were somewhat disturbed, this storm ended at 07^h, September 27. Ranges: *D*, 26′; *H*, 135 gammas; *Z*, 150 gammas.

Albert K. Ludy, *Observer-in-Charge*

Tucson Magnetic Observatory

July to September, 1940

(*Latitude* 32° 14′.8 *N., longitude* 110° 50′.1 *or* 7^h 23^m.3 *W. of Gr.*)

July 3-6—A moderate storm began at about the 12^h GMT, July 3, and lasted until about 24^h, July 6. The storm was without prominent features and both beginning and ending were indefinite.

July 13-16—At 08^h GMT, July 13, a sharp increase in H was followed by small rapid variations in H and D superposed on longer-period changes for about eight hours. This was followed by a bay in H with minor activity in H and D continuing until about 05^h, July 16.

September 26-27—At 17^h 03^m GMT, September 26, a storm began with a sharp increase in H of 45 gammas and a sharp decrease in D, followed immediately by a reversal in both. A decrease in H of about 140 gammas was followed by a return to normal followed by a bay in H that lasted to the end of the storm at 07^h, September 27. The storm was characterized by small, rapid changes in D and H, those in H being superposed on the larger, slower changes.

Roland F. White, *Observer-in-Charge*

Alibag Magnetic Observatory[1]

April to June, 1940

(*Latitude* 18° 38'.3 *N., longitude* 72° 52'.3 *or* 4^h 51^m.5 *E. of Gr.*)

April 25-26—A moderate disturbance began at 02^h 04^m GMT, April 25, with a sudden rise of 31 gammas in H. At 02^h 45^m, April 25, H reached its maximum and then began to fall. The vibrations became larger after 17^h, April 25. The minimum in H was attained at 21^h 32^m, April 26. Ranges: D, 8'.0; H, 154 gammas; Z, 46 gammas.

May 23-25—A disturbance of moderate intensity began at 17^h 53^m GMT, May 23, with a sudden rise of 51 gammas in H. After three minutes H began to fall with oscillations till 20^h, May 23, and then rose rather slowly. The maximum in H was reached at 03^h 30^m, May 24, after which the oscillations became more pronounced and H began to fall with occasional rise here and there. The minimum in H was reached at 13^h 39^m, May 24, and the disturbance ended at 03^h, May 25. Ranges: D, 7'.7; H, 175 gammas; Z, 54 gammas.

June 14-15—A moderate disturbance began at 08^h 01^m GMT, June 14, with a sudden rise of 13 gammas in H. Reaching its maximum at 08^h 04^m, June 14, H began to fall with oscillations to reach its minimum at 20^h 43^m, June 14. The disturbance practically ended at 00^h, June 15. Ranges: D, 7'.1; H, 155 gammas; Z, 35 gammas.

June 25-26—A storm of great intensity began at 02^h 54^m, GMT, June 25, with a sudden rise of 1'.0 in westerly D and 18 gammas in H and a fall of 8 gammas in Z. Small-period vibrations continued till 09^h, June 25, when oscillations became more pronounced. Maximum in H occurred at 08^h 50^m, June 25. Thereafter H fell with small fluctuations till 09^h.5, June 25, after which the conditions became more disturbed. Minimum in H was reached at 15^h 56^m, June 25. Conditions continued to be disturbed till 20^h, June 25, when they became quieter. The storm practically ended at 07^h, June 26. Ranges: D, 13'.9; H, 340 gammas; Z, 96 gammas.

M. R. Rangaswami

Department of Terrestrial Magnetism,
Bombay Observatory, India

[1]Communicated by Dr. S. R. Savur, Director, Bombay and Alibag Observatories.

HUANCAYO MAGNETIC OBSERVATORY

JULY TO SEPTEMBER, 1940

(*Latitude* 12° 02′.7 *S., longitude* 75° 20′.4 *or* $5^h 01^m.4$ *W. of Gr.*)

July 13—There was a sudden commencement at $08^h 00^m$ GMT, July 13, which was followed by a moderate disturbance lasting until 19^h.

August 3—A moderate disturbance of short duration was recorded between 14^h and 19^h GMT, August 3, during which interval the *K*-index was 7.

August 9—A mild disturbance of short duration occurred between the hours 12^h to 15^h GMT, August 9.

September 26—A mild disturbance immediately following a sharp rise in *H* was recorded between 17^h and 22^h GMT, September 26.

H. W. WELLS, *Observer-in-Charge*

APIA OBSERVATORY

JULY TO SEPTEMBER, 1940

(*Latitude* 13° 48′.4 *S., longitude* 171° 46′.5 *or* $11^h 27^m.1$ *W. of Gr.*)

September 26-27—A sudden commencement occurred at $17^h 03^m$ GMT, September 26, with an increase of 29 gammas in *H* and 11 gammas in the numerical value of *Z*. The three elements were moderately disturbed until 07^h, September 27. The range in *H* was 82 gammas.

H. BRUCE SAPSFORD, *Acting Director*

WATHEROO MAGNETIC OBSERVATORY

JULY TO SEPTEMBER, 1940

(*Latitude* 30° 19′.1 *S., longitude* 115° 52′.6 *or* $7^h 43^m.5$ *E. of Gr.*)

July 13-14—This very moderate disturbance began with small, sharp movements in all three elements at $08^h 00^m$ GMT, July 13. The initial impulse was not as abrupt as those usually classed as sudden commencements, since it took but three minutes for completion; nevertheless the impulse undoubtedly marked the beginning of the storm. The only noteworthy feature of the disturbance was a large increase in westerly declination between $12^h 14^m$ and $12^h 28^m$, July 13, amounting to 16′.3. Slightly disturbed conditions prevailed until 18^h, July 14. Ranges: *D*, 21′.1; *H*, 122 gammas; *Z*, 124 gammas.

September 25-29, 1940—This disturbance, of comparatively long duration was, taken as a whole, of only moderate intensity but it has some noteworthy features. The extent of the activity was somewhat disappointing considering the abruptness and magnitude of the early movements; the course of the disturbance is, chronologically, as follows: From $15^h 42^m$ to $15^h 50^m$ on September 25 there is a series of rapid fluctuations of very small amplitude (about 3γ in *H*). The period of these fluctuations is shown by the la Cour quick-running trace to be about 75 seconds. At $16^h 41^m$ on the same day similar fluctuations occur but in this case the values of the elements are also rapidly changing so that by $17^h 00^m$ the horizontal intensity has increased by 61γ, the vertical intensity has decreased by 39γ, and the westerly declination has decreased by 5′.3. This movement has the general appearance of a modified "sudden commencement" but is more probably closely associated with

solar activity which, however, owing to the time of its occurrence it was impossible to observe at Watheroo. The usual quiet period ensued and 25 hours after the initial movement, at $17^h\ 03^m$ on September 26, the sudden commencement of disturbed conditions of the Earth's magnetic field occurred. This movement was of unusually large amplitude and of great suddenness, particularly in H (within two minutes the horizontal intensity had increased by 76γ; the vertical intensity decreasing during the same period by 16γ). For 11 hours following this commencement the traces were disturbed, but not unduly so. There is a large "bay" centering, in H, at $18^h\ 04^m$ and in Z at $18^h\ 17^m$ on September 27, but apart from this the traces throughout September 27, 28, and 29 are only very moderately disturbed. A further "bay" is shown centering, in H, at $14^h\ 06^m$ and in D and Z at $14^h\ 00^m$ on September 29 and this marks the conclusion of the disturbance as the traces thereafter show their normal diurnal variations. Ranges: H, 204 gammas; Z, 87 gammas; D, 15′.4.

W. C. Parkinson, *Observer-in-Charge*

NOTES

25. *Observatorio del Ebro* The Director of the Observatory of the Ebro, Tortosa, Spain, R. P. Antonio Romañá, S.J., advises us that the distribution of the "Boletin Mensual" has been resumed. The work of the Observatory has suffered considerably as a consequence of the war but the instruments for observations of terrestrial magnetism and earth-currents are undergoing repairs and it is hoped that they will again be in regular operation in the near future. The apparatus for observing the potential-gradient, however, was so seriously damaged that the resumption of the atmospheric-electric work will depend upon the replacement of these instruments.

26. *Magnetic Survey of the United States*—The field-work in connection with the publishing of the "Alaska magnetic tables and magnetic charts for 1940" and "Magnetic declination in the United States in 1940" has been completed by the United States Coast and Geodetic Survey with the exception of a few isolated repeat-stations. Despite the large number of stations which had been lost or magnetically disturbed, it is thought the distribution of the observations has been unusually good. The data from many intermediate stations occupied by observers attached to triangulation-parties during the past few years also will be available to assist in determining a better distribution of the declination-values.

27. *Sitka and Tucson observatories*—The old observatory at Sitka, Alaska, has now been abandoned, the personnel moving into their quarters at the new site on October 2, 1940. The magnetographs are still operated in the temporary variation-building pending the drying out and curing of the piers in the new permanent building.

A reconditioned Cooke magnetometer with cobalt-steel magnets was standardized at Cheltenham and sent to Tucson as a standard instrument for that Observatory.

28. *Atmospheric electricty at Canberra*—We learn from the report of the Director of the Commonwealth Solar Observatory, Mount Stromlo, Canberra, that the records of the potential-gradient were continued un-

til January 1, 1940, making a total of thirteen years of observation at one site. They were then discontinued as it was judged that no new information could be gained by further continuance of the series. Some preliminary experiments were made with an apparatus for continuously recording the electrical conductivity of the air. It was intended to use this apparatus in connection with an investigation on ion-mobility, and later for work on atmospheric ionization-equilibria, but this work has been suspended pending completion of other investigations.

29. *Magnetic results, Batavia, 1935-38*—The following table contains the mean values of the magnetic elements obtained at Batavia, Java, during the years 1935-38. Those for 1935 and 1936 are corrected preliminary values and those for 1937-38 are preliminary values derived from the absolute determinations at Batavia.

Element	Year			
	1935	1936	1937	1938
Declination (D)	+ 1° 08′.9	+ 1° 11′.6	+ 1° 13′.9	+ 1° 15′.0
Inclination (I)	−32° 21′.0	−32° 18′.7	−32° 21′.0	−32° 26′.0
Horizontal intensity (H)	0.37038	0.37047	0.37041	0.37039
North-south component (X)	0.37031	0.37038	0.37033	0.37031
East-west component (Y)	+0.00742	+0.00772	+0.00796	+0.00808
Vertical component (Z)	−0.23460	−0.23431	−0.23462	−0.23536
Total force (F)	0.43843	0.43834	0.43846	0.43884

30. *Corrigenda*—In the September 1940 number of the JOURNAL the following corrigenda are noted: On page 252, in the seventh line preceding Section 3, read "$A_t = 2\pi\bar{\omega}_t^2 c_t/\bar{\omega}$" instead of "$A_t = 2\pi\bar{\omega}_t c_t^2/\bar{\omega}$"; on page 272 the first sentence after Table 1-B should read "(0 to 5)^h; A_L is the lunar effect" instead of "(0 to 5)^h; A is the lunar effect."

31. *Personalia*—Upon the death of Lieutenant Commander *G. C. Jones* of the San Juan (Puerto Rico) Observatory, as reported in the September issue of the JOURNAL, Commander *H. A. Cotton* was placed temporarily in charge of the Observatory again. Commander Cotton directed the administrative work from New York City with only a brief return to San Juan. The observations and routine of the Observatory and supervision of the Works Progress Administration project were carried on by *J. W. Roberts*, the observatory assistant, until the arrival of the new officer, Lieutenant Commander *R. L. Schoppe*.

P. G. Ledig, Observer, Department of Terrestrial Magnetism, Carnegie Institution of Washington, arrived at the Huancayo Magnetic Observatory, Huancayo, Peru, on October 11, 1940. He took charge of the Observatory on November 1, 1940, succeeding the present observer-in-charge *H. W. Wells*, who returned to Washington November 19.

Professor *Leonids Slaucitajs* has been appointed Director of the Institute of Geophysics and Meteorology of the University of Latvia, Riga, beginning June 1940.

Dr. *William Bowie*, President of the International Union of Geodesy and Geophysics, 1933-36, and in charge of the Division of Geodesy of the United States Coast and Geodetic Survey, 1909-36, died in Washington, D. C., August 28, 1940, at the age of 68 years.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Apia Observatory. Annual report for 1936. Issued under the authority of the Hon. D. G. Sullivan Minister of Scientific and Industrial Research. Wellington, E. V. Paul, Govt. Printer, 143 pp. (1940). 25 cm.

Annual report for 1937. Issued under the authority of the Hon. D. G. Sullivan, Minister of Scientific and Industrial Research. Wellington, E. V. Paul, Govt. Printer, 131 pp. (1940). 25 cm.

Bartels, J. Solar radiation and geomagnetism. Terr. Mag., **45**, No. 3, 339-343 (1940).

Geophysikalisches Institut, Potsdam. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 85-86 (1940).

Bestimmung täglicher internationaler erdmagnetischer Charakterzahlen für Jahre vor 1890. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 183-195 (1940).

Bartels, J., N. H. Heck, and H. F. Johnston. Geomagnetic three-hour-range indices for the years 1938 and 1939. Terr. Mag., **45**, No. 3, 309-337 (1940).

Bartels, J., and H. F. Johnston. Some features of the large geomagnetic tides in the horizontal force at Huancayo. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 272-287 (1940).

Geomagnetic tides in horizontal intensity at Huancayo. Part I. Terr. Mag., **45**, No. 3, 269-308 (1940).

British National Committee. Report of the British National Committee 1936-39. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 94-108 (1940). [Contains (A) Terrestrial magnetism. (1) Royal Observatory, Greenwich (Abinger); (2) Observatories of the Meteorological Office; (3) R. R. S. "Research"; (4) Theoretical researches; (5) Ionospheric investigations. (B) Atmospheric electricity. (1) Kew Observatory; (2) Electric charges on rain; (3) Thundercloud discharges and atmospheric disturbances; (4) Lightning and the spark discharge.]

Burmeister, F. Erdmagnetisches Observatorium Fürstenfeldbruck (Oberbayern). Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 88-89 (1940).

Chapman, S., and J. Bartels. Geomagnetism. Oxford, Clarendon Press, xxv+542, x+543-1049 (1940). [v. 1, Geomagnetic and related data; v. 2, Analysis of the data and physical theories.]

Chapman, S., and V. C. A. Ferraro. The theory of the first phase of a geomagnetic storm. Terr. Mag., **45**, No. 3, 245-268 (1940).

Christchurch Magnetic Observatory. Annual reports for 1934, 1935, 1936. Wellington, E. V. Paul, Govt. Printer, ix+131 and 1 page of curves (1940). [Issued under the authority of the Hon. D. G. Sullivan, Minister of Scientific and Industrial Research.]

Collinder, P. On compass testing in Sweden especially with regard to the detection of iron in compass bowls. Hydrogr. Rev., **17**, No. 1, 59-67 (1940).

Coulomb, J. Sur le lien entre les phénomènes solaires et magnétiques. Trans. Washington Meeting 1939, Internat. Union. Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 391-393 (1940).

Davidson, W. F. The magnetic storm of March 24, 1940—Effects in the power system. Edison Elec. Inst. Bull., **8**, No. 7, 365-366, 374 (1940).

Debrach, J. Rapport sur les travaux de la Section de Magnétisme et Electricité Terrestres [au Maroc] depuis la réunion d'Edimbourg de l'U. G. G. I. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 117-118 (1940).

Dijk, G. van. The magnetic character of the year 1939 and the numerical magnetic character of days, 1939. Terr. Mag., **45**, No. 3, 351-352 (1940).

Rapport sur les travaux magnétiques [en Hollande] 1936-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 109-110 (1940).

Rapport sur la publication du caractère magnétique de chaque jour. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 177-178 (1940).

Rapport sur la publication du caractère magnétique numérique des jours. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 178-179 (1940).

Rapport sur la publication des caractères magnétiques pendant l'Année Polaire 1932-1933. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 180-181 (1940).

Report on international magnetic classification of Greenwich days prior to 1906. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 181-182 (1940).

Eblé, L. Rapport de la Section de Magnétisme et Electricité Terrestre au Congrès de Washington (1939). Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 77-84 (1940). [This report covers the period June 1, 1936 to March 1, 1939.]

Eckhardt, E. A. Importance of the development of new observational technique for land magnetic measurements. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 547-549 (1940).

Egedal, J. Accurate determinations of the magnetic declination and inclination. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 532-534 (1940).

Errulat, F. Central bureau for magnetic data. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 534 (1940).

Farnham, F. C. Description of Missouri School of Mines Magnetic Observatory. Abstract, Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 311 (1940).

Fleming, J. A. Researches in terrestrial magnetism and electricity at Department of Terrestrial Magnetism, Carnegie Institution of Washington, for year April 1939 to March 1940. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 322-325 (1940).

Trends of research in terrestrial magnetism and electricity. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 41-61 (1940). [Address of the President of the International Association of Terrestrial Magnetism and Electricity, presented at the meeting of September 8, 1939.]

Report by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, to the Washington Assembly on work done since the Edinburgh Assembly. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 147-161 (1940).

Report of committee to consider existing and desirable distribution of magnetic and electric observatories and the better coordination of work and publications of existing observatories. Trans. Washington Meeting, 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 196-204 (1940).

Report of committee for study of relations between solar activity and terrestrial magnetism. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 224-226 (1940).

Progress-report of the joint committee of the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization and the Association on methods and codes to adequately describe magnetic disturbances and perturbations. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 286-291 (1940).

Geomagnetic research in the Americas. Nature, **146**, 273-274 (Aug. 24, 1940). [Abstract of a paper presented to Section VI (Physical and Chemical Sciences) of the Eighth American Scientific Congress.]

Fleming, J. A., E. A. Johnson, and A. G. McNish. Palaeomagnetic investigations. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 535 (1940).

Germaine, L. W. The magnetic storm of March 24, 1940—Effects in the communication system. Edison Elec. Inst. Bull. **8**, No. 7, 367-368 (1940).

Harradon, H. D. Report of committee on classification of magnetic literature. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 267-274 (1940).

Hasegawa, M. Provisonal report on the statistical study on the diurnal variations of terrestrial magnetism and the North Polar Regions. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 311-318 (1940).

Heck, N. H. Magnetic work of the United States Coast and Geodetic Survey, April 1939 to March 1940. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 325-328 (1940).

Progress of work in terrestrial magnetism of the United States Coast and Geodetic Survey July 1, 1936, to June 30, 1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 142-147 (1940).

Howe, H. H. Height of magnetic anomalies. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 309-311 (1940).

Isaev, S. The magnetic storm of April 17, 1939. Prob. Arktiki, Leningrad, No. 5, 102 (1939). [Russian text.]

Jenny, W. P. The magnetic method and its interpretation problems. Internat. Oil, 53-57 (July 1940).

Johnson, E. A. A design for a traveling electromagnetic standard. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 325-332 (1940).

A possible method of measuring the effect of particle emission on the Earth's magnetic field. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 544-547 (1940).

Jones, H. S. Wide-range magnetograph at Abinger Observatory. Terr. Mag., **45**, No. 3, 371 (1940).

Committee on magnetic charts (organization of the work). Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 258-262 (1940).

Joyce, J. W. Report of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, 1936-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 136-137 (1940).

Joyce, J. W., and H. E. McComb. Improvements in methods of field-observations in the United States of America. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 393-404 (1940).

Kalinowski, St. Travaux de l'Observatoire Géophysique de Świder. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 118-123 (1940).

Keränen, J. Report on work in terrestrial magnetism and electricity [in Finland] in 1937-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 73-75 (1940).

Report of the committee on the methodology of magnetic charts. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 262-263 (1940).

Knapp, D. G. An extension of the Dewey decimal classification for terrestrial magnetism. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 272-283 (1940).

Labrouste, M. et Mme. H. Etude comparative en divers points du Globe de la déclinaison cycle undecennal. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 319-324 (1940).

La Cour, D. Rapport sur les travaux magnétiques [en Danemark] 1936-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 69-71 (1940).

Report of committee to promote international comparisons of magnetic standards. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 283-286 (1940).

La Cour, D., and S. Chapman. Report of the committee on registration in Iceland of giant pulsations. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 263-265 (1940).

Lazarev, P. P., N. I. Leuschin, N. N. Nikolsky, N. V. Pushkov, and N. N. Trubyatchinsky. Report on work in terrestrial magnetism and electricity [in U. S. S. R.] during 1936-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 162-176 (1940).

Lee, F. W., and J. H. Swartz. Magnetic studies of the Florida Peninsula. Abstract, Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 297-301 (1940).

Lettau, H. Geophysikalische Warte in Königsberg Pr. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 92 (1940).

Lindholm, F. Observations at Sveagruvan during the Polar Year 1932-1933. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 131 (1940). [Brief progress report.]

Ljungdahl, G. S. Magnetic measurements on the *Kompass* in the Baltic Sea 1938. Stockholm, Kungl. Sjökarteverket, Jordmag. Pub. No. 13, 21 pp. 5 pls. 31 cm. [This publication contains the results of magnetic observations made on the first expedition of the *Kompass* which was launched in the spring of 1938. This vessel, built entirely of oak, has no iron between the galley and engine room. Length 17.5 m, beam 5.4 m, depth 2.4 m, displacement about 50 tons, and speed 7.5 knots. On her first expedition in 1938, D, H, and Z, were measured at 143 stations.]

Magnetic work carried out by the Hydrographic Service of Sweden (Kungl. Sjökarteverket) in 1936, 1937, and 1938. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 131-132 (1940).

McComb, H. E., and J. W. Joyce. Improvements in technique at magnetic observatories in the United States of America. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 404-413 (1940).

McNish, A. G. Magnetic storms. Edison Elec. Inst. Bull., **8**, No. 7, 361-364, 370 (1940).

Physical representations of the geomagnetic field. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 287-291 (1940).

The magnetic storm of March 24, 1940. Terr. Mag., **45**, No. 3, 359-364 (1940).

First report on coordinated study of volcanic phenomena at Santa María. Initial geomagnetic work. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 537-540 (1940).

McNish, A. G., and E. A. Johnson. Determination of the secular variation in declination in New England from magnetic polarization of glacial varves. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 339-347 (1940).

McNish, A. G., and H. F. Johnston. Study of the severe magnetic storm of April 1938. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 348-353 (1940).

MADWAR, M. R. Report on work done on terrestrial magnetism at Helwan Observatory during 1936-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 72-73 (1940). [Contains table of magnetic declinations at repeat stations in Egypt (1937-1939).]

MAURAIN CH. Commission relative au mode de publication des observations magnétiques. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys. Ass. Terr. Mag. Electr., Bull. No. 11, 265-267 (1940).

MOLIN, K. Report of the magnetic survey work of the mainland of Sweden carried out by the Geological Survey of Sweden. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 132-133, (1940).

NAGATA, T. Some physical properties of the lavas of volcanoes Asama and Mihara. II. Magnetic susceptibility. Bull. Earthquake Res. Inst., Tokyo Imp. Univ. **18**, Pt. 1, 102-135 (1940). [English text with Japanese summary.]

NELSON, J. H. Wide-range magnetograph at Cheltenham Magnetic Observatory. Terr. Mag., **45**, No. 3, 371-372 (1940).

NORINDER, H. Report on work in terrestrial magnetism and atmospheric electricity [in Sweden] since the Edinburgh Assembly. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 129-130 (1940). [Brief note.]

OGG, A. Progress of work in terrestrial magnetism. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 124-129 (1940). [This report on the magnetic work in South Africa is divided into two sections: (1) Secular variation stations, and (2) A new magnetic observatory near Cape Town.]

ÓGYALLA. Bulletin mensuel de l'Observatoire Royal pour la Météorologie et le Magnétisme terrestre à Ógyalla, mai à novembre 1939. Budapest, Obs. R. Mét. Mag. Terr., **1**, Nos. 5-11, pp. 41-110 (1939). [Contains results of potential-gradient observations and departures of the hourly values of the magnetic declination from the monthly mean.]

OKADA, T. Observations of terrestrial magnetism, atmospheric electricity, and earth-current at the magnetic observatories in Kakioka and Toyohara, Japan. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11. 114-116 (1940).

PRINCIPAL MAGNETIC STORMS. April to June, 1940. Terr. Mag., **45**, No. 3, 379-385 (1940). [Storms reported for Alibag Magnetic Observatory are for January to March, 1940, and those reported for Watheroo Magnetic Observatory are for March to June, 1940.]

RÉTHLY, A. Bericht über das Kön. Ung. Meteorologische und Erdmagnetische Observatorium zu Ógyalla. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 110-114 (1940).

RIO DE JANEIRO, OBSERVATÓRIO NACIONAL. Anuário publicado pelo Observatório Nacional do Rio de Janeiro para o ano de 1940. Ano LVI. Rio de Janeiro, Imprensa Nacional, xiii+460 (1940). 18 cm. [Contains tables of values of the magnetic declination at different points in Brazil reduced to epoch 1940.0 and an isogonic map of Brazil for January, 1935.]

ROMAN, I. The evaluation of magnetic anomalies by means of scales. Abstract, Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 319-321 (1940).

SECULAR VARIATION. Report of special committee on magnetic secular variation. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 226-242 (1940).

SPIESS, F. Deutsche Seewarte, Hamburg, Gruppe Erdmagnetismus. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 87-88 (1940).

STEWART, R. M. Magnetic results in Canada. Terr. Mag., **45**, No. 3, 344 (1940).

SUCKSDORFF, E. Report regarding research work at the Geophysical Observatory of Sodankylä in 1937-1939. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 75-76 (1940).

Thellier, E. Contribution à la recherche de la variation séculaire du champ magnétique terrestre. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 535-537 (1940).

Toperczer, M. Erdmagnetisches Observatorium, Wien-Auhof der Zentralanstalt für Meteorologie und Geodynamik zu Wien. Trans. Washington Meeting 1939, Internat. Union Geod. Geophy., Ass. Terr. Mag. Electr., Bull. No. 11, 90-91 (1940).

Vestine, E. H. Note on surface-field analysis. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 291-297 (1940).

The disturbance-field of magnetic storms. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 360-381 (1940).

The potential of the Earth's magnetic secular variation. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 382-391 (1940).

Vestine, E. H., M. A. Tuve, and E. A. Johnson. Various hypotheses regarding the origin and maintenance of the Earth's magnetic field. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 354-360 (1940).

Woollard, G. P. A comparison of magnetic, seismic, and gravitational profiles on three traverses across the Atlantic Coastal Plain. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 301-309 (1940).

B—Terrestrial and Cosmical Electricity

Alfvén, H. Reports of investigations of the cosmic radiation carried out at the Research Institute of Physics of the Royal Academy of Science, Stockholm. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 130-131 (1940).

Bak, M. A., i N. N. Nikolaevskaja. Molnija i ee fizicheskaja priroda. Usp. Fiz. Nauk, **22**, No. 3, 294-356 (1939). [Russian text. Lightning and its physical nature.]

Bergvall, R. C., and E. Beck. Lightning and lightning protection on distribution systems. Elec. Eng., **59**, No. 8, 442-448 (1940).

Byers, H. R. General meteorological aspects of thunder-storm electricity. Terr. Mag., **45**, No. 3, 345-350 (1940).

C., H. E. Auroral notes, February to April, 1940. Met. Mag., **75**, No. 893, 94-96 (1940).

Cooper, D. Fine structure in the directional intensity of cosmic rays. Phys. Rev., **58**, No. 4, 288-292 (1940).

Davies, F. T., and G. R. Wait. Densities of condensation-nuclei over the North Atlantic Ocean. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 457-459 (1940).

Fleming, J. A. Electric characterization of days used in connection with publication of atmospheric-electric data from Watheroo and Huancayo. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 254-258 (1940).

Forbush, S. E. On the 27-day and 13.5-day waves in cosmic-ray intensity and their relation to corresponding waves in terrestrial-magnetic activity. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 438-452 (1940).

Gibert, A. Cosmic rays and Poisson's law. Nature, **146**, 198 (Aug. 10, 1940).

Gish, O. H. The distribution of electric elements in the atmosphere near the Earth's surface. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 314-316 (1940).

Report of the committee for the electrical characterization of days. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 242-254 (1940).

First report on coordinated study of volcanic phenomena at Santa María. Initial geoelectric work. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 541-543 (1940).

GISH, O. H., AND K. L. SHERMAN. Ionic equilibrium in the troposphere and lower stratosphere. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 474-491 (1940).

GUPTA, R. L. S. Specific ionization of cosmic-ray particles. Nature, **146**, 65-66 (July 13, 1940).

HEITLER, W., C. F. POWELL, and H. HEITLER. Absorption of heavy cosmic-ray particles. Nature, **146**, 65 (July 13, 1940).

HERZOG, G., AND W. H. BOSTICK. Pair production of mesotrons at 29,000 feet. Phys. Rev., **58**, No. 3, 278 (1940).

HESS, V. F. The discovery of cosmic radiation. Thought, Fordham Univ. Q., **15**, No. 57, 225-236 (1940).

Die Physik der kosmischen Strahlung. Zürich-Leipzig, Orell Füssli Verlag, 86 pp. (1940). [Reprinted from "Die Weltraumstrahlung (Kosmische Strahlung) und ihre biologische Wirkung" von J. Eugster unter Mitarbeit von V. F. Hess.]

JESSE, W. P. A study of time-variations in cosmic-ray intensity at high altitudes. Phys. Rev., **58**, No. 4, 281-287 (1940).

KOENIG, H. P. The solid angle subtended by the main and shadow cones of cosmic radiation. Phys. Rev., **58**, No. 5, 385-386 (1940).

LOUGHRIDGE, D. H., AND P. F. GAST. Further investigations of the air-mass effect on cosmic-ray intensity. Phys. Rev., **58**, No. 7, 583-585 (1940).

MERCANTON, P. -L. A propos de résistivité en prospection électrique: Une pratique à rejeter. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 543-544 (1940).

NARIMATU, A., AND Z. SIGETA. On the periodicity of thunderstorm. J. Met. Soc. Japan, **18**, No. 7, 239-241 (1940). [Japanese text with brief English abstract on p. (26).]

NISHINA, Y., Y. SEKIDO, H. SIMAMURA, AND H. ARAKAWA. Cosmic-ray intensities in relation to cyclones and anticyclones. Nature, **146**, 95 (July 20, 1940).

NISHINA, Y., H. ARAKAWA, Y. SEKIDO, AND H. SIMAMURA. Cosmic-ray intensities and fronts. J. Met. Soc. Japan, **18**, No. 8, 256-258, (28) (1940). [Cosmic rays as a possible meteorological factor, III. Japanese text with English abstract.]

Cosmic-ray intensities and typhoons. J. Met. Soc. Japan, **18**, No. 8, 258-261, (28)-(29) (1940). [Cosmic rays as a possible meteorological factor, IV. Japanese text with English abstract.]

NOLAN, J. J. The equilibrium of ionization in the lower atmosphere. Proc. R. Irish Acad., A, **46**, No. 7, 77-90 (1940).

NOLAN, P. J. Estimation of the air-earth current. Proc. R. Irish Acad., A, **46**, No. 6, 65-75 (1940).

NORINDER, H. Investigations of atmospheric electric discharges at the Institute for High Tension Research (Institutet för Högspänningsforskning) of the University of Uppsala. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 133-134 (1940).

POLAND, J. F., AND R. B. MORRISON. An electrical resistivity-apparatus for testing well-waters. Trans. Amer. Geophys. Union, Pt. 1, 35-46 (1940).

QUENEY, P. Nouveaux types de compteurs d'ions atmosphériques pour la détermination directe du spectre de mobilités. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 455-457 (1940).

ROONEY, W. J. Variation in earth-current activity with the sunspot-cycle. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 467-473 (1940).

RUST, W. M. Typical electrical prospecting methods. Geophysics, **5**, No. 3, 243-249 (1940).

SCHLUMBERGER, M. The application of telluric currents to surface prospecting. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 467 (1940).

Schremp, E. J., and A. Banõs, Jr. On the fine structure pattern of cosmic rays at Mexico City. Phys. Rev., **58**, No. 7, 662-663 (1940).

Sherman, K. L. Total and uncharged nuclei at Washington, D. C. Abstract, Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 316-317 (1940).

Smosarski, W. Mesures comparatives de la conductibilité de l'air. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 454 (1940).

Störmer, C. Report of the Auroral Committee. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 204-222 (1940). Appendix to report, *ibidem*, pp. 223-224.

Torreson, O. W., and G. R. Wait. Need for measurements to supplement observations of potential-gradient and of conductivity at atmospheric-electric observatories. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 460-466 (1940).

Wait, G. R. Report of possible errors in connection with the use of ion-counters. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 300-302 (1940).

Wait, G. R., and O. W. Torreson. Some meteorological effects and their relation to the electrical condition of the lower atmosphere. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 491-499 (1940).

Whipple, F. J. W. Recent progress in the investigation of thunder-storms. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 473-474 (1940).

C—Miscellaneous

Appleton, E. V. Some recent ionospheric researches. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull No. 11, 516-521 (1940).

Dissipative processes for electrons in the ionosphere. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 523-526 (1940).

Appleton, E. V., and L. V. Berkner. Joint committee of the Association of Terrestrial Magnetism and Electricity for collaboration with International Scientific Radio Union. First report to the Seventh General Assembly at Washington. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 292-297 (1940).

Barnett, S. J. Gyromagnetic ratios for ferromagnetic substances: New determinations and a new discussion of earlier determinations. Proc. Amer. Acad. Arts Sci., **73**, No. 14, 401-455 (1940).

Barsch, O. Kommission zur geophysikalischen Reichsaufnahme. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 92-93 (1940).

Berkner, L. V. Observatory technique of ionospheric measurements. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 417-437 (1940).

Problems of upper atmospheric physics. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 500-502 (1940).

Berkner, L. V., and S. L. Seaton. Ionospheric measurements during the solar eclipse of April 7, 1940. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 311-314 (1940).

Booker, H. G., and S. L. Seaton. Relation between actual and virtual ionospheric height. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 503-515 (1940).

Brunner, W. Provisional sunspot-numbers for May and June, 1940. Terr. Mag., **45**, No. 3, 338 (1940).

Final relative sunspot-numbers for 1939 and monthly means of prominence-areas for 1931-1939. Terr. Mag., **45**, No. 3, 365-367 (1940).

CHAPMAN, S. Report on international collaboration to advance the study of the Moon's effect upon geophysical phenomena. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 297-299 (1940).

COLLINDER, P. On the variation in the magnetic moment of the compensating magnets, with a simplified method of observation. Hydrogr. Rev., **17**, No. 1, 68-78 (1940).

DARROW, K. K. Introduction to the ionosphere. Proc. Amer. Phil. Soc., **83**, No. 2, 429-445 (1940).

Analysis of the ionosphere. Bell System Tech. J., **19**, 455-488 (1940). [This paper, in abbreviated form, appeared in Elec. Eng., **59**, 272-283 (1940).]

FLEMING, J. A. Statement summarizing transactions of the Washington meeting of the International Association of Terrestrial Magnetism and Electricity. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 10-15 (1940).

Suggested lines for further investigations of upper-air physics. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 527-531 (1940).

GILLILAND, T. R., S. S. KIRBY, AND N. SMITH. Characteristics of the ionosphere at Washington, D. C., April, 1940, with predictions for July, 1940. Proc. Inst. Radio Eng., **28**, No. 6, 276-277 (1940).

Characteristics of the ionosphere at Washington, D. C., May, 1940, with predictions for August, 1940. Proc. Inst. Radio Eng., **28**, No. 7, 332-333 (1940).

HARRADON, H. D. List of recent publications. Terr. Mag., **45**, No. 3, 388-392 (1940).

HEILAND, C. A. Preliminary report on magnetic and electrical laboratories in new Geophysics Building, Colorado School of Mines. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 137-142 (1940).

HULBURT, E. O., E. A. JOHNSON, AND M. A. TUVE. Problems of the intermediate atmosphere. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 526-527 (1940).

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS. Association of Terrestrial Magnetism and Electricity. Transactions of Washington meeting, September 4-15, 1939. Edited by A. H. R. Goldie in collaboration with J. W. Joyce. Edinburgh, Neill and Co., viii+556 (1940). 25 cm. [Contains: Agenda and minutes, national reports, special reports, proposals on various subjects, resolutions, committees, and reporters.]

IRELAND, G. Sunspots and telephone service. Solar disturbances which influence both the Kennelly-Heaviside layer and earth-currents probably cause magnetic storms like that which affected electrical communications last March. Bell Telephone Q., **19**, No. 3, 184-196 (1940).

JOHNSON, E. A., AND W. F. STEINER. Measurement of susceptibility of materials used in magnetometers. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 333-339 (1940).

JOHNSTON, H. F. American URSI broadcasts of cosmic data, with American magnetic character-figure C_A, April to June, 1940. Terr. Mag., **45**, No. 3, 373-377 (1940).

JOUAUST, R. L'étude des évanouissements brusques des ondes radioélectriques courtes. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 413-416 (1940).

KIRBY, S. S. Ionosphere research of the National Bureau of Standards during 1939. Trans. Amer. Geophys. Union, 21st annual meeting, Pt. 2, 328-329 (1940).

KIRBY, S. S., N. SMITH, AND F. R. GRACELY. Characteristics of the ionosphere at Washington, D. C., June, 1940, with predictions for September, 1940. Proc. Inst. Radio Eng., **28**, No. 7, 334-335 (1940).

The ionosphere and radio transmission, July, 1940, with predictions for October, 1940. Proc. Inst. Radio Eng., **28**, No. 8, 378-379 (1940).

Kriuchkov, S. The physics of the ionosphere of an undisturbed day. Moscow, Bull. Acad. sci., No. 1, 125-128 (1940). [Russian text with English summary.]

La Cour, D. Report on the activity of the Polar Year Commission of the International Meteorological Organization. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 302-303 (1940).

Report on photographic reproduction of records. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 303-310 (1940). [On pp. 304-310 appears list of registerings, observations, photographs, and discussions regarding magnetism, earth-current, cosmic radiation, and aurora, collected for the use of investigators.]

Lasareff, P. Sur les principes généraux de la cartographie géophysique. Moscow, Bull. Acad. sci., No. 1, 2-16 (1940). [Texte russe avec résumé français.]

McPetrie, J. S., and A. C. Stickland. Reflection curves and propagation characteristics of radio waves along the Earth's surface. J. Inst. Elec. Eng., **87**, No. 524, 135-145 (1940).

Mainka, K. Oberschlesische erdwissenschaftliche Landeswarte in Ratibor. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 93-94 (1940).

Massey, H. S. W. Recombination and attachment processes in the ionosphere. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 521-523 (1940).

Mount Wilson Observatory. Summary of Mount Wilson magnetic observations of sunspots for May and June 1940. Pub. Astr. Soc. Pacific, **52**, 295-298 (1940).

National Bureau of Standards. Averages of critical frequencies and virtual heights of the ionosphere, observed by the National Bureau of Standards at Washington, D. C., April to June, 1940. Terr. Mag., **45**, No. 3, 372-373 (1940).

Nettleton, L. L. Geophysical prospecting for oil. New York, McGraw-Hill Book Co., Inc., xi+444 (1940). 23 cm. [The magnetic and electric methods of geophysical prospecting are discussed in parts II and IV, respectively.]

Newton, H. W. Early visual observations of bright chromospheric eruptions on the Sun's disk. J. Brit. Astr. Ass., **50**, 273-278 (1940).

Nicholson, S. B., and E. S. Mulders. Solar and magnetic data, April to June, 1940, Mount Wilson Observatory. Terr. Mag., **45**, No. 3, 377-378 (1940).

Rothé, E. Le rôle de la radioactivité dans les roches. Abstract, Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 453-454 (1940).

Shchukin, A. The unsolved problems of the physics of the ionosphere. Moscow, Bull. Acad. sci., No. 1, 129-131 (1940). [Russian text with English summary.]

Thiessen, A. D. The founding of the Toronto Magnetic Observatory and the Canadian Meteorological Service. J. R. Astr. Soc. Canada, **34**, No. 7, 308-348, 4 pls. (1940).

Weickmann, L. Geophysikalisches Observatorium am Collmberg bei Oschatz. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 93 (1940). [Brief note.]

Wells, H. W. Multifrequency recordings of radio-wave polarization near the geomagnetic equator. Terr. Mag., **45**, No. 3, 353-358 (1940).

Whipple, F. L. The density of the upper atmosphere from photographic meteors. Trans. Washington Meeting 1939, Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 11, 499-500 (1940).

Wright, H. L. Atmospheric opacity at Valentia. Discussion. Q. J. R. Met. Soc., **66**, No. 285, 209-213 (1940).